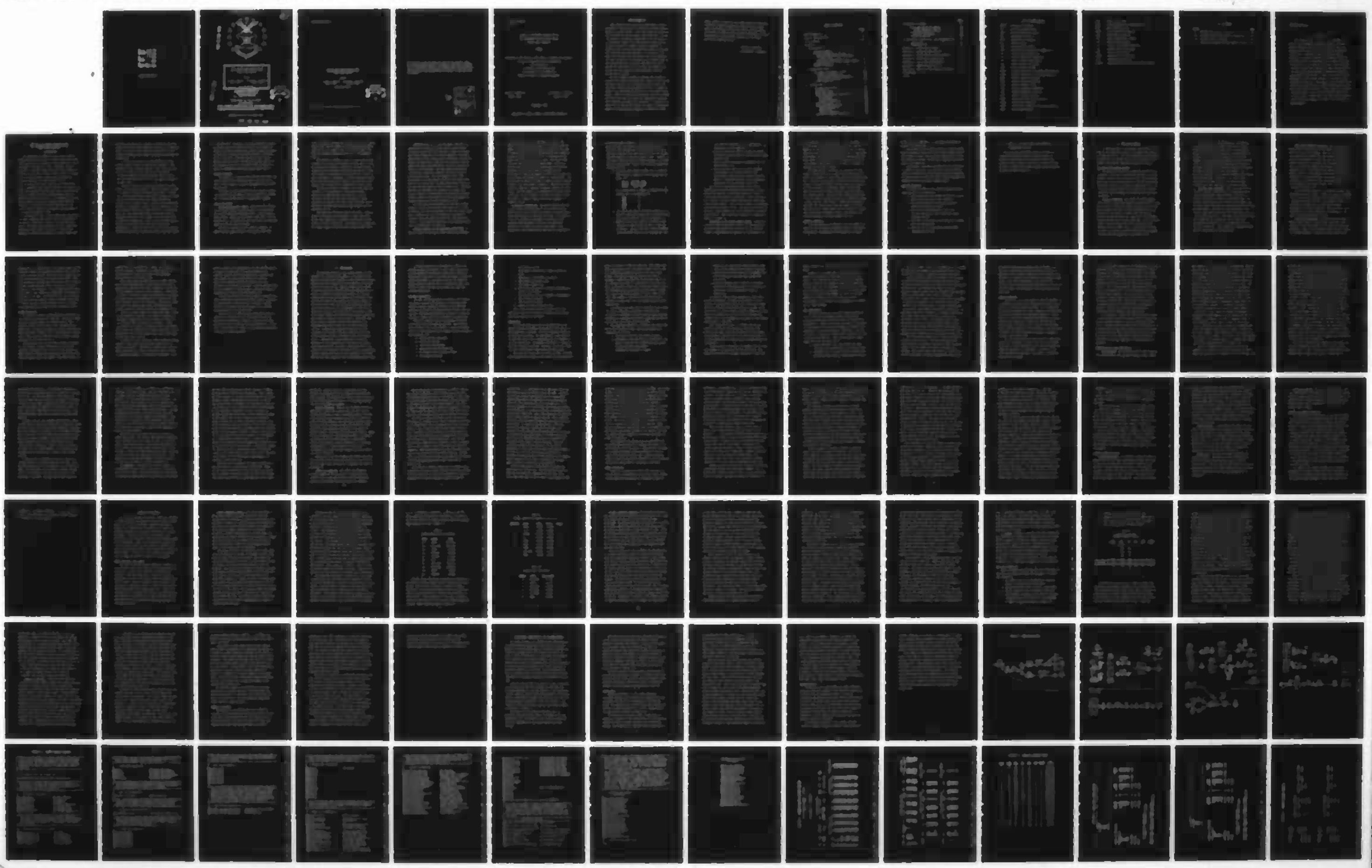
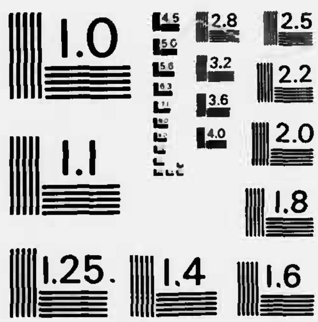
AD-A148 448   IMPACT OF ACTIVATION OPTIMIZATION ON THE VANDENBERG GROUND SUPPORT SYSTEM..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI..   1/2

UNCLASSIFIED   G R BENFIELD ET AL. SEP 84   F/G 22/4   NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

2

IMPACT OF ACTIVATION OPTIMIZATION ON THE VANDENBERG GROUND SUPPORT SYSTEM USING Q-GERT ANALYSIS

THESIS

Gerald R. Benfield
Major, USAF

Christopher J. Budinsky
Captain, USAF

AFIT/GSM/LSY/84S-3

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GSM/LSY/84S-3

IMPACT OF ACTIVATION OPTIMIZATION ON THE VANDENBERG GROUND SUPPORT SYSTEM USING Q-GERT ANALYSIS

THESIS

Gerald R. Benfield
Major, USAF

Christopher J. Budinsky
Captain, USAF

AFIT/GSM/LSY/84S-3

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the authors and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

AFIT/GSM/LSY/84S-3

IMPACT OF ACTIVATION OPTIMIZATION ON THE VANDENBERG GROUND SUPPORT SYSTEM USING Q-GERT ANALYSIS

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Systems Management

Gerald R. Benfield
Major, USAF

Christopher J. Budinsky
Captain, USAF

September 1984

Approved for public release; distribution unlimited

Acknowledgements

This thesis could not have been undertaken let alone completed on time without the continued assistance and moral support of several people. First and foremost we would both like to thank our faculty advisor, Major Rod Byler. He not only agreed to accept the responsibility for advising us in this momentous endeavor but went above and beyond the call of duty to secure the computer resources necessary to compose, edit, and print the completed document (at minimum cost, both pecuniary and temporal). In this same vain, Major Ron Rasch and LCDR Bob Cathcart are to be commended for their cooperation in allowing us to be "guinea pigs" on the new Burroughs word processor. We would also like to express our gratitude to Dr. Dick Fenno, who supported us during the final stages of word processing to achieve letter-quality status.

We are extremely grateful to Captain John Vonloh and Captain Steve Hogan from AFOTEC/LG4S. They not only had the courage to sponsor us in our thesis effort but took time from their already busy TDY schedule to fly in to WPAFB to assist us in the design and execution of our Q-GERT network model. Major Joe Coleman was invaluable, both as our Q-GERT instructor and later as a source of debugging our program and refreshing our memories in statistics. In addition, we would like to thank Major Coakley, who spent a considerable amount of time and effort helping us to debug our Q-GERT

model. Special thanks go to Ms. Diana Haynes for patiently fielding our numerous questions during the never-ending quest for perfection in style and format. Finally, thank you Katrina and Penny (and our respective families) for your encouragement, understanding, patience, and all those qualities we married you for.

Gerald R. Benfield

Christopher J. Budinsky

Table of Contents

List of Abbreviations

ANOVA	Analysis of Variance
AO	Activation Optimization
BSM	Booster Separation Motors
DF	Disassembly Facility
DOD	Department of Defense
ET	External Tank
GSS	Ground Support System
HMCF	Hypergolic Maintenance and Checkout Facility
ILC	Initial Launch Capability
IOC	Initial Operational Capability
KSC	John F. Kennedy Space Center
MOS	Mission Operations System
MPS	Main Propulsion System
NASA	National Aeronautics and Space Administration
OMCF	Orbiter Maintenance and Checkout Facility
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
PCR	Payload Changeout Room
PIE	Payload Integration Equipment
PMD	Program Management Directive
SCA	Shuttle Carrier Aircraft
SDF	Safeing and Deservicing Facility
SLC-6	Space Launch Complex 6
SPSS	Statistical Package for the Social Sciences
SRB	Solid Rocket Booster

SRM	Solid Rocket Motor
SRSF	SRB Refurbishment and Subassembly Facility
SSF	SRB Storage Facility
SSME	Space Shuttle Main Engines
SSV	Space Shuttle Vehicle
STS	Space Transportation System
TBL	Time Between Launches
TCF	External Tank Checkout Facility
TPS	Thermal Protection System
TVC	Thrust Vector Control
VAFB	Vandenberg Air Force Base
VLS	Vandenberg Launch Site
VSTAR	Vandenberg Shuttle Turnaround Analysis Report

List of Tables

Abstract

The purpose of this research was to determine the impact of the changes made to the Vandenberg AFB Ground Support System by Activation Optimization; in particular determining the annual launch rate from the Vandenberg Launch Site. A simulation approach, using a Q-GERT analysis, was taken to accomplish the research objective. A Q-GERT model of the Vandenberg Ground Support System was developed and, once validated, the output used to determine the annual launch rate. Analysis of these results indicated that the Ground Support System, as changed by Activation Optimization, would be able to meet the Air Force Program Management Directive (PMD) schedule of launches for the Vandenberg Launch Site. This analysis also revealed several potential bottlenecks in the system, identifying the launch pad as the primary constraint. Further sensitivity analysis indicated, however, that for the Vandenberg Launch Site to be able to meet a higher launch rate than seven launches per year the physical expansion of certain facilities must be accomplished.

IMPACT OF ACTIVATION OPTIMIZATION ON
THE VANDENBERG GROUND SUPPORT SYSTEM
USING Q-GERT ANALYSIS

I. Introduction

The Department of Defense has described the Space Transportation System (STS) as "a Space System that allows launch and recovery of reuseable launch vehicles in lieu of the present 'one time only' use of expendable launch vehicles." It further states that the primary purpose of the STS is to provide a greater access to space at a lower cost than existing space payload launch systems and considers the STS a national resource (18:1).

The STS has now been in operation for three years. With 11 successful Space Shuttle missions to its credit, the STS is fulfilling the National Space Policy directive that it be the primary method for launching NASA, DOD, and commercial payloads into orbit. It is imperative that the STS be operated in the most efficient manner possible because it is considered to be the "backbone of this nation's space transportation system for the remainder of this century and beyond" (6:49).

Since March of 1981, all STS flights have originated at the John F. Kennedy Space Center (KSC) and terminated at Edwards AFB, California. Recently, the tenth mission, STS-10, terminated at KSC making it the first completely operational "space port" in the world. KSC has been assigned all initial STS operations, orbital flight test

launches, and operational launches on equatorial and near equatorial orbits (which comprise the majority of commercial uses). For polar or near polar and the majority of DOD payloads, Vandenberg AFB (VAFB) was chosen as the second STS launch site.

In order for the STS to be cost effective, a high annual launch rate must be achieved and sustained. Many parameters have a potential impact on this launch rate but none will be more critical than that of the ground turnaround process for the Space Shuttle Vehicle (SSV), which has been identified as "one of the keys to success of the STS" (3:41).

Currently KSC has all facilities necessary to accomplish this turnaround process. Similar facilities at VAFB are included in the Ground Support System (GSS). Originally, the GSS operations at VAFB were to be similar to those of KSC to include all operational tasks necessary to receive, store, process, launch, recover, and refurbish the SSV and its subsystems. However, due to a reduction in the Space Shuttle launch rate at VAFB from 20 to 4 launches per year (22), and tightening economic conditions leading to budgetary constraints (17), changes to the GSS facilities at VAFB were necessitated. The Air Force and NASA jointly conducted the Offload Study (now called Activation Optimization), during the first half of FY 82, "to optimize Vandenberg facilities" resulting in several baseline changes

to the GSS (22). In general, the Study identified specific facilities within the VAFB GSS which will be completely deleted (activities accomplished at KSC), partially deleted (only certain activities performed at VAFB), or deferred until a later date. Although the VAFB Initial Launch Capability (ILC) is still scheduled for October 1985, full GSS capability will not be available until July 1987 as a result of implementing Activation Optimization (AO)(1).

Problem Statement

The problem is to specifically determine the annual SSV launch rates from the Vandenberg Launch Site (VLS) as a result of the changes to the GSS, implemented by Activation Optimization.

In order to reach a solution to this problem a simulation approach will be taken to develop a model of the VAFB GSS incorporating the Activation Optimization changes.

Literature Review

Space Transportation System. The entire STS consists of five major systems: a Mission Operations System (MOS), the Payload Integration Equipment (PIE), a Ground Support System (GSS), a Space Shuttle Vehicle (SSV), and a Payload System (18:1). Of these five, the SSV and GSS have the most impact on the STS turnaround time.

The SSV is composed of four separate elements. A manned Orbiter (Space Shuttle), and External Tank (ET)

containing the propellants used on ascent by the three Space Shuttle Main Engines (SSME), and two Solid Rocket Boosters (SRB) make up the complete SSV. The Orbiter, SSMEs, and SRBs are reuseable components while the ET is expendable (18:1).

The orbiter is similar in size to a DC-9 aircraft with a length of 122 feet, a wing span of 78 feet, and a 15 X 60 foot payload bay capable of carrying up to 65,000 pounds. A commander and pilot/mission specialist comprise the normal crew; however, accommodations are available for a total of six crew members or passengers. The Main Propulsion System (MPS) used during launch is located in the aft end of the Orbiter and is fueled by the propellants in the ET (18:1).

The ET is 27.5 feet in diameter, 154.2 feet long, and contains all the propellants (1.55 million pounds) necessary for SSME operation during launch. The ET separates from the Orbiter after the required ascent trajectory is reached, falls back toward the ocean, and is designed to break-up and burn-up during re-entry into the atmosphere (18:4).

The SSMEs are used during launch and ascent. Each of these three engines is approximately 14 feet long with a nozzle about eight feet in diameter and produces 375,000 pounds of thrust at sea-level. The engines can be gimballed for flight control during the Orbiter ascent phase (18:4).

Completing the SSV are the twin SRBs. They burn in parallel with the MPS to provide initial ascent thrust lifting the entire SSV to an altitude of about 27.5 miles. Each SRB is comprised of six primary elements: the Solid Rocket Motors (SRM), forward and aft structures, operational flight instrumentation, separation and recovery avionics, separation motors and pyrotechnics, and the Thrust Vector Control (TVC) subsystem. Each SRB weighs approximately 1.289 million pounds and produces a sea-level thrust of 2.65 million pounds. The cone shaped aft skirt (aft structure) of the SRB supports the entire SSV weight load while on the launch pad. The SRB is separated from the ET by eight Booster Separation Motors (BSM) (18:4). Since the SRB and its components are reuseable, once separation occurs, descent is accomplished by the parachute recovery system, located in the forward structure, consisting of a ribbon drogue and three main parachutes (18:5).

The GSS has been determined to be the most critical element in terms of a sustained SSV launch rate (11:203). In general, the VAFB GSS consists of "the facilities, equipment, software, services and organization necessary to perform the ground operations tasks" for SSV turnaround (14:4). A more detailed discussion of the Vandenberg GSS will be accomplished in Chapter II.

<u>Mission Scenario at the Vandenberg Launch Site</u>. A brief overview of the typical Space Shuttle cycle begins

with the installation of the mission payload into the Orbiter. Next the launch sequence is initiated by Orbiter SSME firing followed by SRB firing and lift-off. The SRBs are separated after burnout and recovered using a parachute system and recovery vessel. The ET is separated shortly before the Orbiter reaches final orbit. The Orbiter then fires the Orbital Maneuvering System (OMS), attains the desired orbit, and carries out mission/payload operations. Meanwhile, the recovered SRBs are disassembled and processed, the empty SRM segments returned to the vendor and the remaining SRB assemblies readied for refurbishment. The Orbiter then re-enters and lands at VAFB and begins safeing, checkout, and refurbishment procedures. Other ETs and SRBs already at VAFB are inspected, assembled, checked out, and tested. The SRB segments and assemblies are stacked on the launch pad, the ET is mated to the SRBs and finally, after the Orbiter is mated to the ET, the entire sequence is repeated (18:15).

Activation Optimization. Activation Optimization (AO) is the current term being used for the Offload Study in which the Air Force and NASA participated for approximately nine months during the 1981-1982 time frame. The objective of AO is to "determine programmatic alternatives that optimize VAFB development, activation and operations consistent with specified mission requirements" (22). Essentially, "AO represents what NASA can do in the way of

processing flight hardware for Vandenberg to obtain some short and long term benefits for the Air Force" (13). Initially, the VAFB GSS was to be similar to that of KSC with refurbishment of all SSV reuseable components, except SRM case segments, being accomplished at VAFB. However, as previously indicated, several baseline changes to the VAFB GSS were necessitated. Overall, the following changes have resulted from AO:

1. The early Space Shuttle launch rate for VAFB has been revised to conform to the following mission model (24):

STS-1V	October 1985
STS-2V	April-July 1986
STS-3V	February 1987
STS-4V	July 1987

   The proposed model by number of launches per year through 1991 is as follows (20):

1985	1
1986	1
1987	4
1988	1
1989	3
1990	4
1991	4

2. Full VAFB Space Shuttle processing capabilities to include launch and landing will be available under this mission model for the July 87 launch (1).

3. VAFB activation will support an average of four launches per year during the 1985 to 1993 time frame (22). (The current USAF Program Management Directive (PMD) calls for four launches per year

with facility capacity for five, and growth to ten launches per year by 1989 (7).)

4. KSC will process the Orbiter through the Orbiter Processing Facility (OPF) for the first three VAFB launches (19).
5. KSC will perform parachute refurbishment for all VAFB launches (13).
6. KSC will perform SRB forward and aft assembly refurbishment for all VAFB launches (19).
7. The Hypergolic Maintenance and Checkout Facility (HMCF) is completely deleted, and all hypergolic maintenance will be performed at KSC (19).

As a result of the Offload Study, the Air Force developed the following evaluations/conclusions in early 1982 concerning what is currently termed AO: first, it allows the concentration of resources in areas critical to ILC; second, it does not affect the ability to meet the current mission model; third, AO will result in significant cost deferrals/savings (21:12). The focus of this research will be on the determination of the validity of the second AO conclusion. The actual GSS at VAFB will be addressed in detail in Chapter II.

<u>Simulation of the Ground Support System</u>. "Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of

evaluating the various strategies . . . for the operation of the system" (16:2). Shannon (16:4) further describes a model as "a representation of an object, system, or idea in some form other than that of the entity itself." This means that changes can be made to the model to simulate possible "real world" conditions, in order to analyze the effect of these changes, which might not be practical or possible to implement on the actual system.

The VAFB GSS is a system and the simulation of this system, through the use of a model, will provide decision makers with a method to understand, analyze, and improve the GSS. This GSS is essentially a network of activities comprised of a series of queues (waiting lines) all leading to the final product of a completed, ready to launch SSV. Certain activities within the GSS also involve procedural and random elements. Therefore, due to these characteristics, and others discussed in Chapter II, Q-GERT was chosen to model the GSS. Additionally, Q-GERT was designed and developed for studying the procedural aspects of defense systems (15:vii), among others, and can be used in conjunction with project management aspects, risk analysis, and decision making for solving problems (15:viii).

Research Objective

Existing models of the VAFB GSS (2,9) are almost two years old and are based on information prior to Activation Optimization. Consequently, these models are no longer

valid for predicting GSS turnaround times and ultimately launch rate capabilities.

The purpose of this research will be to develop a model of the Vandenberg Launch Site Ground Support System based on the changes resulting from Activation Optimization in order to objectively evaluate the GSS and to ascertain the annual launch rate capability.

Additionally, the model developed will not only be able to predict launch rates, but can also be used to identify possible bottlenecks in the GSS system allowing "management" to reduce/alleviate these bottlenecks thereby increasing the system efficiency and further reducing costs.

Research Questions

In order to accomplish the research objectives several questions need to be addressed:

1. What assumptions are necessary to develop a network model within the scope of the research?
2. How detailed must the network be in order to effectively evaluate the GSS?
3. Which of the GSS subsystems, if any, are binding constraints on the launch rate, after implementing AO?
4. What data is available on the GSS and AO to update previous assumptions?
5. What will be the time between launches after implementation of AO?

6. What is the annual launch rate capability after implementation of AO?

Having briefly defined the problem, provided the necessary background information and stipulated the objectives and questions to be answered through this research effort, the next chapter will further define and describe the VAFB Ground Support System and the simulation technique chosen to model it.

II. System Description

An important part of the problem formulation, the first step of the simulation process, is to define the system to be simulated (16:26). The following detailed description of the VAFB GSS will specify what is and is not part of the system, and establish applicable boundary conditions.

The VAFB Ground Support System

As previously indicated the VAFB GSS consists of the components, facilities, and resources necessary to receive, process, recover, and turnaround the SSV. The processing phase can be further sub-divided into receiving, handling, inspecting, checkout, and recovery operations (18:5). The entire GSS can be divided into four basic areas: Orbiter processing, SRB processing, ET processing, and Launch Pad processing.

Orbiter Processing. The Orbiter processing begins after either a normal end-of-mission landing at VAFB or with delivery of an Orbiter on a Shuttle Carrier Aircraft (SCA). Upon landing, after roll-out and post-landing servicing operations, the Orbiter is towed to the Safeing and Deservicing Facility (SDF) for completion of the necessary safeing operations and on-board data dump. From the SDF the Orbiter is then towed to the Orbiter Maintenance and Checkout Facility (OMCF) (12:9). If the Orbiter arrives via SCA, it is taken to the Mate/Demate Facility, demated from the SCA, and transferred to the OMCF (12:13).

The OMCF contains all equipment, low and high bay structures, support and storage areas, and all other facilities and services necessary for the maintenance, repair, refurbishment, modification, payload/mission kit integration, and functional checkout of the Orbiter systems. At the same time the Thermal Protection System (TPS) is repaired or replaced, payloads are removed, if necessary (18:15), and the hypergolic modules are removed and sent to KSC for maintenance and checkout (19). Following functional and integrated systems tests, payloads requiring horizontal installation are received and installed in the OMCF (18:5). The Orbiter is then transported to the launch pad for mating with the ET.

External Tank Processing. Due to the size of the ET, the only currently feasible mode of transporting the ETs from the manufacturer, Martin-Marietta Corporation in Michoud, Louisiana, to VAFB is by sea-going barge. The barges, carrying one ET, will travel via the Panama Canal to the South VAFB docking facility where the GSS ET processing sequence begins. The ETs are then transported to the External Tank Checkout Facility (TCF) and placed in one of four storage bays (11:81). The tanks are stored until they are scheduled to be transported to the launch pad. Preliminary ET checkout is to be accomplished prior to arrival at VAFB (19). Final checkout is accomplished when the ET is positioned on the launch pad.

Solid Rocket Booster Processing. The SRB processing begins with the recovery of the two SRBs from the ocean and their arrival at Port Hueneme. Upon arrival at the port, the parachutes are washed down and prepared for shipment to KSC for refurbishment. At the same time the SRBs are safed, washed, deserviced, and taken to the Disassembly Facility (DF). At the DF the segments are cleaned, packed, and shipped by rail to the manufacturer, Thiokol Corporation in Ogden, Utah, for refurbishment and refilling (12:75). The remainder of the SRB components, the forward and aft skirt assemblies, are cleaned, packed, and shipped to KSC for refurbishment, Thrust Vector Control (TVC) hotfire, and functional checkout (19).

The processing continues at the SRB Refurbishment and Subassembly Facility (SRSF), at VAFB, as incoming components arrive, either as new hardware from the manufacturer or as refurbished hardware from KSC. All hardware is then inspected and assembled into completed aft booster assemblies and forward assemblies. Then the aft and forward assemblies, and the SRM segments are transported to the launch pad and stacked/mated (12:69).

Launch Pad Processing. The launch pad processing at Space Launch Complex 6 (SLC-6) begins immediately after launch with the refurbishment of the launch pad and support equipment. Next, the SSV assembly begins with the stacking of the SRB components. During the latter stages of this

process, the ET is transported to the Payload Changeout Room (PCR) and attached to a strongback handling fixture, which is used to support the ET. The entire PCR is then moved on its tracks to position and mate the ET to the SRBs. Then the strongback is released and the PCR moved back to repeat the same process with the Orbiter, mating it to the ET. Payloads are then installed, if not accomplished previously in the OMCF. Final checks are accomplished and terminate in the launch of the SSV. Following lift-off, ground systems are deactivated and secured, safety and damage inspections conducted, and when conditions permit, SLC-6 is reopened for normal work and the entire cycle is repeated (12:41).

Q-GERT Simulation

As previously stated, Q-GERT simulation techniques are very suitable for modeling the VAFB GSS. Basically, Q-GERT utilizes a systems approach to problem solving. This approach consists of four steps: first, decomposing the system into its significant elements; second, analyzing and deservicing these elements; third, integrating the elements into a model; fourth, assessing system performance through evaluation of the model (15:viii).

Q-GERT uses an activity-on-branch network philosophy. In this network, a branch represents an activity that involves a processing time or a delay (15:3). Similar to PERT networks, branches are separated by nodes which can be used as decision points and queues. The Q-GERT network is a

combination of these nodes and branches. Transactions, physical objects, information, or a combination of the two, flow through the network according to the branching characteristics of the nodes (15:3).

When transforming the VAFB GSS into a Q-GERT network, the various SSV components are the transactions flowing through the system with the nodes representing the various service/assembly facilities of the components. Additionally, Q-GERT can be used to model the simultaneous processing of several parallel SSV components all flowing toward the final assembly point at the launch pad. Essentially Q-GERT is a more than adequate application relating queueing systems analysis to project planning and management (15:5).

There are several aspects of Q-GERT which make it ideal for the modeling of the GSS. With respect to analysis of the system, Q-GERT allows for the automatic collection of five different types of statistics (15:66-67). These statistics will be useful in determining where bottlenecks exist, which GSS components are binding constraints, and for determination of an annual launch rate, one of the primary objectives of this research.

Q-GERT also has the ability to identify specific transactions in the system and mark these transactions for specific operations. Additionally, Q-GERT can be used to hold transactions at a specific node until other related transactions elsewhere in the system are completed. This

permits separate parts/assemblies to be put together and not released as a whole until both parts/assemblies are complete. Q-GERT also has the capability to specify the time between activities/nodes according to several distribution methods, thereby allowing for the most "realistic" distribution to be used. Finally, Q-GERT allows for the assignment of either single or multiple servers to represent the various service activities (15).

The reasons listed above are the primary considerations used in choosing the Q-GERT simulation technique. Additional considerations include the ease with which a Q-GERT network can be modeled and the availability of a Q-GERT operating system on a local computer.

Having now fully described the system under study, it logically follows that the next step should be that of defining the methodology necessary to realize the stated objectives of this research. This methodology will, therefore, be developed with respect to the previously described technique of Q-GERT simulation.

III. Methodology

As expressed previously, the primary purpose of this research is to determine the impact of the changes implemented by Activation Optimization on the VAFB Ground Support System turnaround capabilities and consequently on the SSV launch rate from the VLS. Research objectives have been stated and associated research questions formulated so as to assist in defining the system under study. In order to address these objectives and answer these questions a methodology of simulation was chosen, as stated in Chapter I. Having specified, then, the goals and objectives, and defined the boundaries of the system, the next step in the simulation process is the formulation of the model of the "real world" system. This model should neither oversimplify the system nor simulate too much detail. Therefore, the model should be designed "around the questions to be answered rather than imitate the real system exactly" (16:27). To meet these "modeling objectives" certain assumptions must be made about the system to attain the desired balance between oversimplification and excessive detail. Additionally, these assumptions will assist, somewhat, in the determination of the data to be used in describing the model, the inputs to the model, and in the analysis of the outputs of the model, as well as determining specific aspects about the various subsystems of the VAFB GSS and the interconnections and relationships between them.

It is the objective of this chapter to define the primary variables of interest in this study, discuss the various assumptions formulated concerning the VAFB GSS, describe the data used in the model development, discuss the actual development of the model, describe the completed model, discuss procedures used to validate the model, and finally, briefly describe how the model will meet the research objectives.

Variable Description

In order to meet the research objective, the primary information desired from the model is the average time between launches (dependent variable) of the VAFB GSS, needed to calculate an average annual SSV launch rate from the VLS. The model developed must, therefore, be able to produce an output capable of providing this information.

There are numerous factors (independent variables) which affect the launch rate of the SSV. Those factors which resulted from or were modified by AO are of primary concern for the purpose of this research and are included in the following list:

1. Orbiter landing operations
2. Orbiter processing
3. Launch pad refurbishment
4. Launch pad/Countdown operations
5. ET transportation (Michoud to VAFB)
6. ET storage facilities

7. ET production rates
8. SRM segment transportation (VAFB to Thiokol to VAFB)
9. SRM segment refurbishment and refill
10. SRM segment production rates
11. SRM segment useful life
12. SRB forward and aft skirt assembly transportation (VAFB to KSC to VAFB)
13. SRB forward and aft skirt assembly refurbishment
14. SRB storage facilities
15. SRB processing at VAFB
16. Number of shifts worked per week

Since these variables affect the VAFB launch rate capability, they can be altered as required for performing sensitivity analysis on the model.

Assumptions

So that the model will not be oversimplified or too detailed several assumptions concerning the VAFB GSS and its subsystems need to be made. The first assumption concerns the VAFB GSS facilities. For the purpose of this research, the VAFB GSS facilities, as modified by AO, are assumed to be fully operational. Furthermore, the model is concerned only with launches from VAFB. Therefore, the Orbiter, SRBs, and ETs are dedicated to VAFB launch operations only.

The time units chosen for the model are days. Although the available data is given in work hours, it was determined

that a conversion to days was necessary. This change was made to standardize the relationship between 24 hour days for transportation modes and 16 hour days (two 8 hour shifts, five days per week) for service activities. Although a normal seven day week is 168 hours long, it is only 80 work hours long or 11.428 (80/7=11.428) hours per day. Dividing this figure into the assessed times, given in the Vandenberg Shuttle Turnaround Analysis Report (VSTAR) (14), yields the required number of days to complete the task. For example, a task requiring 168 work hours to complete, actually takes 14.7 days (168/11.428=14.7) when standardized.

In addition, the times used in the model do not account for loss of equipment or components resulting from accidents, or management related functions such as holiday scheduling or manpower requirements. These factors are not within the scope of this research project.

The following assumptions, concerning the overall GSS model, are the same as those used by Martin-Marietta Corporation (14:21-23):

1. Turnaround activities are success oriented.
2. Assessments (discussed later in this chapter) are based on approved GSS configurations and do not consider proposed enhancements.
3. Personnel are available on demand.

4. Times are not included for testing support equipment, ground communications network of software.
5. Unscheduled maintenance and TPS refurbishment will be accomplished in parallel with planned OMCF activities.
6. Returned payloads will be removed in the OMCF.
7. Appropriate cleanliness levels of the payload and payload bay will be maintained during all operations.

In addition, the following assumptions, concerning specific subsystems, were made for the purpose of this research. The dedicated Orbiter will be returned to VAFB, either by normal end-of-mission landing or by SCA. Also, the Orbiter will return without excessive damage which would require replacement of the entire Orbiter and that all supplies, parts, and equipment are available for the Orbiter refurbishment in the OMCF.

With regard to the ET, it is assumed that Martin-Marietta Corporation will be able to furnish all ETs necessary for VAFB operations and that sufficient barges, each capable of carrying one ET, are always available. It is also assumed that no unusual enroute shipment delays are encountered.

Concerning the Launch Pad, it is assumed that no extensive damage is incurred during launch operations. The possibility exists that inclement weather will cause some

delays, however, this factor is not incorporated into the model.

Finally, it is assumed that sufficient SRB recovery vessels are available and that they are in place during launch. The transportation functions of the SRM segments and the forward and aft assemblies assume that sufficient railroad cars, for all components, and aircraft, for forward and aft assemblies, are available. It is also assumed that Thiokol can provide refurbishment and refill of the SRM segments on schedule, and that KSC can provide all refurbishment of the forward and aft assemblies on schedule, for all VAFB launches.

Data Description

The data utilized for this model comes from VSTAR 10 (14) in the form of assessments based on KSC ground processing experiences and then tailored to the VAFB GSS configuration. VSTAR 10 provides a timeline for allocation of requirements and a ground processing flow baseline for generation of long range planning. Essentially, the data provided is in the form of times (hours) necessary for each task within the VAFB GSS. There are two specific times associated with each task (14:3):

1. Design Reference Time - the minimum time span allotted for the performance of processing tasks.
2. Assessed Time - the time allotted to perform the processing tasks based on normal possible delays.

For the purpose of this model, assessed times were used because they were judged to more accurately reflect the actual time necessary to complete the processing tasks.

Since the actual system to be modeled is not in operation and the KSC SSV ground processing facilities are different from those planned for VAFB, the exact statistical distribution of the assessed task times is unknown. However, historical data from other programs using assessed times have shown these times to have a lognormal distribution (23). Again, since no actual data is available to compute the parameters of a lognormal distribution necessary for a Q-GERT program, a triangular distribution will be used to approximate the lognormal distribution. The parameters required by Q-GERT for a triangular distribution are a most likely value, an optimistic value, and a pessimistic value (15:61). The assessed time for each processing task will be used as the most likely value. Historical data indicate that optimistic and pessimistic times ten percent shorter and twenty percent longer than the assessed time, respectively, are accurate estimations (23).

Data concerning transportation times was obtained from various sources (2,6,17). The times involving the ET transportation from Michoud, Louisiana to VAFB were given in terms of falling between two values, a maximum and a minimum. This type of data lends itself to the use of a uniform distribution function, assuming that every value

between the minimum and maximum values is equally likely. All other transportation times were given in the form of assessed times, previously addressed in this chapter, and, therefore, a triangular distribution was utilized for these times. Upon final determination of the form of the available data and having already determined the form of the desired output, the development of the actual model is the next step.

Model Development

Initially, in the early stages of model development, it is necessary to ascertain the step-by-step details of how a process is actually performed (16:46). For the VAFB GSS, this means determining the proper sequence of operations for each of the subsystems and subsystem components. Consequently, a flow chart diagram was developed to put each of these process steps into a logical and condensed form. After several iterations a final flow chart was obtained which shows the progress of the processing of SSV components throughout the entire VAFB GSS, from Orbiter landing to launch of the complete SSV.

The flow charting activity also allows for some determination of the amount of detail to be used in the model resulting in further assurance of not "over designing" the model and making it too cumbersome. In addition, flow charting enables manipulation of the model to produce the desired form of output.

Once the proper sequence of the GSS activities has been determined, along with the previous decision as to which components and variables are to be included in the model, the next step is to determine the functional relationships between these activities and the actual values of the parameters to be used to describe these relationships (16:61). This is accomplished by constructing the Q-GERT network (see Appendix A) for the GSS following the flow charted process sequence. The various types of nodes available in Q-GERT permit precise description of these functional relationships. Additionally, the availability of several types of time distributions, as discussed in Chapter I, provide for "realistic" application of transportation and component processing times.

It is possible to begin the GSS process almost anywhere in the system and produce the desired output (average time between launches) needed to calculate the annual launch rate. This model sequence begins with the splashdown of the reuseable SRBs directly after launch and ends with the SSV launch and mission. This sequence also provides for easy manipulation of the independent variables allowing for collection of the data necessary for the GSS sensitivity analysis.

VAFB Structural Model Description

SRB Subsystem. The GSS begins with the SRB subsystem. All transactions in this system represent a pair of SRBs,

SRM segments, or forward and aft skirt assemblies. Regular node 3 represents the beginning of SRB recovery operations immediately after launch of the Space Shuttle. Source node 2 is designed to supply node 3 with one SRB arrival transaction just under a month after system startup to depict the system as it would exist at a typical point in time. This initialization will be further explained in the Tactical Research Design subsection. Completion of SRB recovery is realized by arrival of SRB transactions at regular node 4 which represents the Disassembly Facility at Port Hueneme. Here the SRBs are washed, disassembled, safed, deserviced and prepared for shipment. Disassembly is modeled by routing the transaction from node 4 to regular nodes 5 and 6, activities 3 and 4, where attributes are assigned to distinguish the SRM segments from the forward and aft skirt assemblies. Attribute 1, at node 5, assigns a value of one to the segments, and at node 6, a value of two to the skirts. Attribute 2 is used to assign an incremental value to the SRM segments representing the number of times they have been launched. Their useful life is then tracked by the value of the attribute. The useful life of the segments is limited to four launches while it is assumed the forward and aft skirt assemblies have an infinite life.

After the completion of activities 3 and 4, the segments are transported to Thiokol Corporation in Ogden, Utah, and the skirts are transported to KSC in Florida. The

segments are routed through regular node 7 which has conditional take-first branching to check their useful life. If a segment has been used four times, it is discarded at sink node 8 where the appropriate statistics are recorded. Those segment transactions that can be reused arrive at regular node 9, representing the Thiokol factory, where SRM case segments are refurbished while new segments are generated, eventually replacing those that die. Source node 11 generates the new segments for the VAFB GSS at a constant rate of one every 5 months. These segment transactions are then routed to que node 12 representing the Thiokol railhead where refurbished segments are also routed while awaiting shipment to VAFB. Source node 10 initializes the system with four SRM segment transactions. Allocate node 13 allocates one unit of resource 1, railroad cars at Thiokol. This technique assures that no more segments arrive at VAFB than can be stored, or processed in the SRSF. From node 13, each segment transaction is routed to que node 14 which initiates the shipment of SRM segments from Ogden to VAFB. Segment transactions then arrive at que node 15, representing VAFB, where they await further assembly with refurbished forward and aft skirt assemblies.

Activity 8 represents the shipment of the forward and aft skirt assemblies from VAFB, regular node 6, to KSC, regular node 16. Here, the skirts are refurbished and await shipment back to VAFB at que node 18. Source node 17

initializes the system with five SRB skirt transactions. Allocate node 19 allocates one unit of resource 2, railroad cars at KSC. As with the segments, no more skirts can arrive at VAFB than can be stored or processed in the SRSF. From node 19, each skirt transaction is routed to que node 20 which initiates the shipment of SRB skirts from KSC to VAFB. The skirt transactions arrive at que node 21, also representing VAFB, where they are joined by available SRM segments.

Selector node 22, with Assembly Mode Selection (ASM), requires that at least one transaction be in que node 15 and que node 21 prior to joining the SRB components in storage. When this condition is satisfied, the first segment transaction in que node 15 and the first skirt transaction in que node 21 are removed, assembled, and routed to que node 60, which represents arrival at the SRB storage facility. Criterion B/2 is specified at node 22 so that attribute 2, the useful life of the SRM segments, is retained when the assembled set of transactions is routed to the storage facility.

Allocate node 61 allocates one unit of resource 8, storage capacity in the SRB Storage Facility (SSF), which provides enough space for the components of one pair/set of SRBs. When allocated, this transaction proceeds through node 61 to que node 62, the SSF, where it waits to be processed in the SRSF. Allocate node 63 then allows one

unit of resource 9, space in the SRSF, to be allocated up to a maximum of two sets of SRBs. When the transaction arrives at regular node 64, it immediately branches to three separate free nodes whereupon one unit of resource 1, 2 and 8 is freed at allocate nodes 13, 19 and 61 respectively. This allows another SRM segment and skirt transaction to be transported to the newly vacated space in storage. The SRB components then proceed to que node 70 where they await processing, which includes inspection and assembly. Upon completion of processing, the SRB components transaction arrives at que node 68, where it either proceeds directly to the launch pad for stacking or waits for the completion of launch pad refurbishment.

Allocate node 24 allocates one unit of resource 4, Launch Pad capacity, and prevents SRB component transportation to the pad if it's not ready for use. If the pad is ready, the SRB transaction is allocated through node 24 to free node 69, which allows another available SRB to enter the SRSF. Finally, the SRB transaction proceeds to que node 25 which initiates SRB stacking on the launch pad. Upon completion, the stacked SRB assembly transaction waits at que node 26 to be mated to the first available ET.

ET Subsystem. The generation of ETs at Michoud is accomplished at source node 27 with activity 16 producing one ET every 60 days. The ET transactions are then routed to que node 28 representing the storage facility at Michoud.

Allocate node 29 allocates one unit of resource 3, barges, allowing room for one ET unit from storage. This transaction then proceeds to que node 30 which initiates the ocean shipment to VAFB, represented by que node 50. If one of four storage cells is available, as controlled by resource 6, allocate node 51 will allocate one unit of storage space to the incoming ET transaction. Prior to arriving in storage, represented by que node 53, the transaction passes through regular node 52 which simply allows a separate branch, activity 50, to return the barge to Michoud. This branch terminates with the activation of free node 36 which frees up the barge resource at allocate node 29 to transport another ET from storage in Michoud. ETs wait in que node 53 for the allocation of one unit of resource 7, the checkout cell, controlled by allocate node 54. If the cell is vacant, the transaction proceeds immediately through node 54 to free node 56, which frees up space in storage for another ET. Once in the cell, a preliminary check is conducted enroute to que node 58 where, upon arrival, after completion of the check, the ET is mated with an SRB assembly, if available from que node 26.

Selector node 32 assembles the waiting transactions in que nodes 26 and 31 representing an ET/SRB mate. Again criterion B/2 is specified so that attribute 2 is retained by the assembled transaction, which is then routed through free node 57 which frees up the TCF Checkout cell to admit

another ET. Finally, activity 19 represents the time consumed in mating the ET to the SRBs, and performing the dwell process. Upon completion of this activity at que node 34, the ET/SRB awaits the arrival of a refurbished Orbiter for the final subsystem assembly.

Orbiter Subsystem. There is one dedicated Orbiter for VAFB which is generated by source node 90. The initial Orbiter transaction, as well as subsequent Orbiter transactions returning from a mission, are routed to que node 91 where they await towing to the OMCF when it becomes vacant. Allocate node 92 allocates one OMCF resource which, when available, then allows the transaction to be routed to regular node 93, initiating the towing of the Orbiter. Upon arrival at que node 94, representing the OMCF, the Orbiter receives any servicing necessary such as maintenance, repair, refurbishment, payload integration, or functional systems checkout. At the completion of servicing, represented by que node 95, the Orbiter awaits the arrival of a mated ET/SRB set.

Selector node 39 then assembles the ET/SRB transaction from que node 34 and the Orbiter transaction from que node 95, once again using criterion B/2 to maintain the value of attribute 2.

Launch Pad Subsystem. The launch pad subsystem actually begins at service activity 15 where SRBs are stacked on the launch pad and then continues through to selector node 39 where this description will commence.

The assembled set of transactions at selector node 39 then passes through free node 37 which frees up the OMCF represented by allocate node 92. The Orbiter is then towed to the Launch Pad, represented by regular node 38, where it is subsequently mated to the ET/SRB assembly. Once this process is accomplished, the completed transaction arriving at regular node 40 represents the entire SSV. This initiates the final series of launch pad processing activities.

The first of these activities, service activity 22, represents the movement of the Payload Changeout Room (PCR) to the Launch Mount (LM) to support Orbiter servicing and checkout. The transaction then reaches regular node 41 where it passes to service activity 23 the SSV Interface Test (SIT) where operations are performed to verify interface integrity and system compatibility. Once the SIT processing is completed the transaction arrives at regular node 42 where hypergolic servicing, service activity 24, commences. When the hypergolics are serviced on-board the SSV the transaction arrives at regular node 43. At this point the servicing processing is completed and the initial countdown processing/activities begin with service activity 25.

When initial countdown operations are completed the transaction arrives at regular node 44 which depicts probabalistic branching. At this point probability is used to determine if a vertical payload installation must be

accomplished or if the payload has already been installed horizontally while the Orbiter was in the OMCF. Payloads requiring a vertical installation will be accomplished approximately 98% of the time while a horizontal payload will have been installed only 2% of the time (10). If a vertical payload is to be installed, the transaction passes from regular node 44 to service activity 26 representing the installation operations. Once these operations are complete the transaction moves to regular node 46. Other countdown operations continue simultaneously with the installation of the payload. If a payload has already been installed horizontally while the Orbiter was in the OMCF, the transaction would then move from regular node 44 to activity 26 representing the continuation of countdown operations. When these final countdown operations are completed the transaction then passes to regular node 45. Once the transaction reaches either node 45 or 46, it passes immediately to statistics node 47 which represents launch of the SSV. At this node, statistics are collected to determine the amount of time between launches in the system. These statistics will be used to determine the average annual launch rate capability of the VAFB GSS.

After passing node 47 there are three branches the transaction will then follow. The first branch routes the SRBs once they have been separated from the SSV. This branch goes from node 47 back to node 3 reinitiating the SRB

subsystem cycle for this particular set of SRBs. The second branch is activity 30 which represents the Orbiter space mission. When the mission activity is completed the transaction then proceeds to the Orbiter subsystem at node 91 starting the cycle again for this specific Orbiter. Finally, the third branch from node 47 is activity 29 which represents the initial launch pad refurbishment process. When the initial LP refurbishment is completed the transaction passes to free node 48 where the LP, resource 4, is freed. This allows allocate node 24 to assign the LP for use if a transaction is waiting in que node 68. These actions essentially complete one cycle of the VAFB GSS, from SRB recovery and Orbiter landing to the launch of the SSV. The Q-GERT computer program resulting from this model is shown in Appendix B.

The Q-GERT network representing the GSS system was formulated and developed so as to model the system as it would behave in the "real world." Specifically, the steps in the model development were accomplished to insure a logical and consistent form to aid in model validation. These concepts will be further discussed in the next section specifically addressing the validation of the model.

Model Validation

Since it is impossible to prove that any model is a true or correct representation of the real system, Shannon (16:29) describes the process of validation as that of

"bringing to an acceptable level the user's confidence that any inference about a system derived from the simulation is correct." In other words, it is necessary to develop a level of confidence that is acceptable concerning the inferences made from the model's output to the actual "real world" system. It should be noted, at this point, that the model should be evaluated/validated only in terms of the purpose for which it was developed. For the VAFB GSS, this means that the model will be validated only in terms of producing a realistic approximation of the time between SSV launches and consequently an annual launch rate.

Emory (8:128) describes validity as "the extent to which a test [model] measures what we actually wish to measure . . . . the extent to which differences found with a measuring tool [model] reflect true differences among those being tested." In theory, this can be accomplished both internal and external to the model. Externally, this involves matching the model's output or predictions with those of the "real world" system data. However, since the VAFB GSS is not yet completed and operational, and therefore, "real world" data is not available, internal validation is all that can be accomplished at this time.

Shannon (16:236) has stated that validation can also be accomplished through the "professional judgment of the people most intimately familiar with the design and operation of a system," and that this method of validation is

possibly "more valuable and valid than any statistical test yet devised." Therefore, the Air Force Operational Test and Evaluation Center (AFOTEC), Space Systems Logistics Analysis Branch, agreed to assist in the validation of the model used in this research.

The internal validation and verification process involved ensuring that the model behaved as intended and that the model was logical and consistent in form. This type of validation can be considered a continuing process that takes place throughout the entire modeling procedure. There is no such thing as "the test" for validity, and this continuous process throughout the model development is necessary to build up confidence in the model (16:29). During the formulation of the VAFB GSS model, a logical flow of transactions/processes and a consistent application of assumptions and time distributions was utilized to enhance the validity of the model.

These processes of internal validation, mentioned above, fall into two stages (16:215-216). The first of these stages is to determine the face validity of the model followed by the second stage of verifying the assumptions, parameters, and distributions utilized in building the model. This first stage of validation "entails looking at each of the simple processes [GSS subsystems] modeled, [which make up the larger, more complex overall model], to ensure that the building blocks, so to speak, are the best

possible" (16:215). The formulation of the VAFB GSS model adhered to this process. Carefully following a precise definition of the VAFB GSS each of the GSS subsystems, as described in Chapter II, was logically modeled individually. These individual subsystem models were then coded for the computer and run in order to certify that they behaved as anticipated. Running these subsystems separately enabled each of the "service processes" to be easily observed and measured, thereby, allowing for high confidence in their representations (16:215). This additionally provided content validity, as defined by Emory (8:129), for the model by assuring that an adequate and representative coverage of the individual GSS subsystem processes were included in the model. Once the individual subsystem models proved to operate properly, they were then put together to form the larger, more complex VAFB GSS model.

Upon completion of this first stage, the second stage of internal validation commenced; that of verifying the assumptions, parameters, and distributions used in model formulation. If it is possible, an attempt should be made to verify these assumptions, discussed earlier in this chapter, through vigorous emperical testing. It is not necessary, however, that each assumption be empirically testable; but, it is necessary that each assumption "be reasonable, based upon our best knowledge of the system" (16:215). Therefore, those assumptions which lend

themselves to this type of testing, along with the parameters and distributions used in the model, have been previously validated and revised, if necessary, by NASA (13), Martin-Marietta Corporation (12), and AFOTEC (23). Those assumptions which cannot be tested empirically have been analyzed by several experts (10,23) and meet the criteria of being reasonable and consistently applied throughout the model.

Once the entire model was developed and final coding for input into the computer accomplished, several runs were conducted to insure the model behaved as intended. As indicated, this was performed on the individual GSS subsystems and then again on the finalized complete model. Specific aspects of the model were examined during each run: the number of transactions representing each of the SSV components; proper releasing of conditional and probabalistic branching; suitable allocation of resources; correct assembly and integration of the appropriate SSV components; and, timely flow of the transactions throughout the entire system. All of these aspects permit the observation of particular individual service processing functions, and the model as a whole, in order to ascertain if they were performing as they should. This was accomplished through the two Q-GERT trace functions: event and nodal. "An event trace portrays the sequence in which activities are performed [and] a nodal trace portrays the decisions, value

assignments, and branching that occurs ,at a given node" (15:194). Through these trace functions, all of the above aspects of the model were determined to occur in a logical and proper sequence; thereby, providing for confidence in the model.

When the entire model was determined to behave properly, a sensitivity analysis was performed (see Chapter IV). One of the real advantages of simulation is the ease with which this sensitivity analysis can be performed (16:235). Sensitivity analysis involves the systematic variance of the input variables over a particular range of interest to determine the effect on the model's output. This was used to indicate the possible impact of changes in the system's external environment and provide information for possible model modifications to be made later. Additionally, sensitivity analysis was used to determine how to alleviate bottlenecks or inefficient operations which might show up in the system.

Tactical Research Design

System Equilibrium. In an effort to begin the model at system equilibrium, several unsuccessful attempts were made to place the six SRBs that are normally available at the specific locations designated by policy. This placement includes, one SRB in the factory at Thiokol, two SRBs at the railhead at Thiokol and KSC, two SRBs in the SRSF at VAFB and one SRB anywhere in the pipeline. Due to the difficulty

involved in placing these SRBs while assigning attributes to distinguish between SRM segments and forward and aft skirt assemblies, the decision was made to initialize the system at three nodes: regular node 3, and que nodes 12 and 18. The approximate delay necessary to allow the appropriate transactions to flow to the proper initial locations was calculated to be approximately 26 days. This time delay was then specified in field 13 of the GEN card, of the computer program, to designate when to begin keeping statistics. This technique facilitated system equilibrium and avoided startup perturbations.

Autocorrelation. In determining how long to run the model, autocorrelation posed a potential problem. Since one of the main objectives of this research was to determine annual launch rate, it was assumed that one year defined a natural cycle. In order to reduce autocorrelation, a model should be run for at least four times the cycle time (5). To be sure, a ten year run was chosen to preclude the possibility of autocorrelation in the model.

Sample Size. The size of a sample determines the normality aspect. Although 30 runs are recommended to satisfy the Central Limit Theorem, eight is usually sufficient (5). Ten runs were initially used and due to the negligible difference in results between one and ten simulations, a sample size of ten runs was determined to be sufficient.

Variance Reduction. In order to obtain the precision of a large number of runs using only a small number, several variance reduction techniques can be used. Fortunately, the Q-GERT Analysis Program automatically provides correlated sampling using common random numbers from its built-in random number streams.

Meeting the Research Objective

The methodology for formulation of the VAFB GSS model, through the previously described procedures and processes, was developed with the intention of meeting the overall research objective and accompanying research questions (See Chapter I). The resulting simulation model more than adequately supported the research objective (See Chapter V) and throughout this chapter sufficiently addressed all of the research questions. However, a brief summary follows. Addressing research questions 1, 2, and 4 provided the foundation for those procedures utilized in the development of the VAFB GSS model. Once the final model was completed and validated then the model itself provided answers for research questions 3, 5, and 6 (see Chapter IV); resulting in the accomplishment of the overall research objective, as discussed in Chapter V.

In summary, this chapter discussed the variables, assumptions, and data necessary for model formulation, the actual model development, description, and validation, and the research design necessary to avoid statistical errors.

In adherence to a logical approach to this research, the results of the simulation and analysis of these results will be addressed in the next chapter.

IV. Results and Analysis

This chapter addresses the primary results and analysis of these results of the simulation conducted using a Q-GERT model of the VAFB Ground Support System as described in Chapter III. Additionally, the product of a sensitivity analysis, performed on certain key variables, will also be addressed. Initially, an analysis of the model and a discussion of the statistics collected by the Q-GERT program will be presented. This will be followed by a description of the variables chosen for the sensitivity analysis, the sensitivity analysis results, and the statistical testing of these results. Finally, all of the results and analyses will be summarized briefly at the end of this chapter.

Model Operations and Results

The Tactical Research Design subsection of Chapter III discussed the need for the collection of data/statistics to begin after a steady state condition of the model was achieved. This was accomplished in order to preclude a significant variance of the results from the proposed "real world" system. Therefore, several runs of the model were necessary to establish the point in time from which the Q-GERT program would start keeping statistics. These runs determined that a steady state condition was achieved after approximately 26 simulated days of model operation and the data/statistics were collected starting from this point in the model operation.

Q-GERT Simulation Results. The results discussed in this section apply to the fully operational VAFB GSS configuration, as modified by Activation Optimization, and described in Chapter II. The data/statistics automatically collected by the Q-GERT Analysis Program (see Appendix C) fall into five primary categories for this specific simulation: average node statistics, average number and waiting time in Q-nodes, average server utilization, average resource utilization, and average resource availability. Only those particular aspects of these categories which apply to this research will be addressed.

The primary statistic of interest in the average node statistics category is average time between launches, from which a launch rate can be calculated. This number was collected during each run at node 47 in the network and then an average of all values obtained during all runs was computed. This final value indicated an average of 105.5624 days between launches or approximately 3.4577 launches per year from the VLS utilizing the GSS configuration as described in Chapter II. Other statistics of interest from this category are a minimum and maximum observed value of the time between launches over the entire simulation period (10 runs, 10 years each). The observed minimum time between launches was 105.1913 days or approximately a maximum of 3.47 launches per year. The maximum observed time between launches was 106.2129 days or approximately a minimum of 3.4365 launches per year.

Average waiting time in Q-node is the statistic of interest in the next category. This statistic, calculated for each Q-node in the network, is the average waiting time of all simulation runs of the average time of a transaction waiting in a specific Q-node obtained on a single run (15:84). This information can be used to determine where transactions are waiting in queues and the length of time that they are required to wait prior to continuing through the network. This statistic can also be used, in conjunction with the Q-GERT network diagram, to determine where back-ups/bottlenecks are occurring in the system. These bottlenecks will be primarily manifested at the two Q-nodes prior to each of the selector/assembly nodes (nodes 22, 32, 39). A comparison of waiting times at each of these Q-nodes will demonstrate which branch is limiting the assembly of transactions. These values are listed in Table I, along with several additional Q-nodes of interest. Specific values for only those Q-nodes to be analyzed will be addressed.

The remaining categories of statistics are also used, in conjunction with the Q-GERT network diagram, to further refine the determination of possible limiting factors in the system. Average resource utilization and availability are used simultaneously and in association with the Q-node statistics. The statistics from these two categories are an average of all simulation runs of the time weighted average number of resource units in use (utilization) or available

for use (availability) obtained on a single run (15:86). These statistics can be used to determine if a particular resource is limiting or causing a back-up within the system. These values are listed in Table II.

TABLE I

Average Waiting Time in Q-nodes

NODE	LABEL	TIME
15	SRSF	789.9503
18	F&A STOR	160.4942
21	SRSF	0.0943
26	STACKED	0.0000
34	ET/SRB	0.0201
58	TCF	95.9913
62	SRB STOR	84.3181
68	PRE STAK	158.0844
70	SRSF	1.8469
95	ORBITER	9.8904

Average server utilization indicates the utilization of the particular ground support process associated with each Q-node. Since the only Q-nodes of interest are, again, those prior to the selector/assembly nodes it follows that the only servers/processes of interest are those prior to these Q-nodes. This information is also used to further refine the determination of the limiting factors within the network. These values are shown in Table III.

TABLE II

Average Resource Utilization & Availability

RESOURCE	LABEL	UTIL.	AVAIL.	MAX #
1	SEGS	1.0000	0.0000	1
2	F & A	1.0000	0.0000	1
3	BARGE	3.2637	0.7363	4
4	LP	0.9914	0.0086	1
5	OMCF	0.4662	0.5338	1
6	ETSC	3.6124	0.3876	4
7	ETCO	0.9970	0.0030	1
8	SRB STOR	0.8376	0.1624	1
9	SRSF	1.9982	0.0018	2

TABLE III

Average Server Utilization

SERVER	LABEL	UTILIZATION
12	SEG SHIP	0.1467
13	TRAIN	0.1615
14	SRB PROC	0.2026
15	SRB STAK	0.3207
17	ET XPORT	0.4096
92	OMCF	0.3700

Q-GERT Simulation Analysis. The principle objective of this research was to determine the annual launch rate of the VLS through the simulation of the GSS using Q-GERT techniques. The annual launch rate was obtained by dividing the average time between launches into 365 days per year, resulting in approximately 3.4577 launches per year. Since the average time between launches of 105.5624 days does not significantly vary from either the minimum (105.1913 days), or the maximum (106.2129 days) values, it may be assumed that this denotes the reliability of the simulation model and resulting data.

Once the launch rate was calculated the determination of possible bottlenecks within the system was necessary. This was accomplished through the analysis of the average waiting time, average resource utilization and availability, and average server utilization statistics. A comparison of the average waiting time in the Q-node pairs 15 and 21, 58 and 26, 34 and 95, revealed which of the respective network branches was limiting the transaction flow through the network. The Q-node with the shortest waiting time of the two is the slowest branch. This illustrates that as transactions arrive at this specific Q-node, they are almost immediately released to be assembled with the transactions waiting in the other Q-node, having the longest waiting time of the two. Comparison of Q-nodes 15, SRM segments waiting at VAFB for processing, and 21, shipment and refurbishment

of the forward and aft skirt assemblies, shows that the branch associated with node 21 is a possible limiting factor due to its respectively shorter average waiting time. Likewise, comparison of nodes 58, ET waiting for mating to SRBs, and 26, stacked SRBs waiting for an ET, indicates that the continuation of the SRB processing activities, as opposed to ET activities, are still limiting the flow through the system. Finally, comparison of nodes 34, completed ET/SRB processing, and 95, a serviced Orbiter waiting for mate to ET/SRB assembly, indicates that the branch associated with the SRB subsystem is still limiting the flow of transactions through the system.

The connotation is that the SRB subsystem is the primary constraint within the VAFB GSS. However, further analysis is necessary to determine exactly which process or resource within this subsystem is causing this slow down. This further analysis is accomplished through the use of the average resource utilization/availability data. This information shows how much/often a particular resource is utilized through a comparison of the maximum number of resource units and their average utilization in the simulation. The closer the average is to the maximum number the more a resource is utilized. This data also displays how often a resource is available for use.

Commencing with the branch associated with Q-node 21, identified previously as a possible limiting area, is

resource 2, the railroad cars used to ship the refurbished SRB forward and aft skirt assemblies from KSC to VAFB. This data (Table II) indicates that these resources are in continuous use, 100% of the time, and is supported by the resource availability data. Examination of the waiting time (Table I) at the Q-node prior to the resource assignment, node 18, indicates a long average waiting time for the resource to become available; again, confirming a possible bottleneck at this point.

Continuing through the network to the branch associated with Q-node 26, also previously identified as another possible limiting area, shows three resources associated with this branch: resource 8, SRB storage; resource 9, the SRSF; and resource 4, the launch pad. Again, inspection of the data reveals that resource 9 and 4 are almost in continuous use, 99.9% and 99.1% respectively. This is confirmed by the resource availability data with resource 9 being available for use only 0.18% of the time and resource 4 only 0.86% of the time. The data also reiterates the fact that since resource 8 is not in continuous use it is not a limiting factor. Reviewing the waiting time in the Q-nodes prior to resource 9 and 4, nodes 62 and 68 respectively, shows a moderate waiting time for resource 9 and a long waiting time for resource 4. Two conclusions can be drawn from this information. First, because Q-node 68 follows Q-node 62 in the network, it is the former of the two that is

constraining releases from Q-node 62, producing the waiting time in this node. Additionally, since resource 4 follows Q-node 68, it is this resource that is limiting the flow of transactions through Q-node 68 and consequently through this branch. Therefore, the launch pad resource is definitely a limiting factor within the system. Second, even though resource 2 is a possible constraining factor it is providing sufficient transactions to the branch constrained by the launch pad availability. This demonstrates that in the present GSS configuration resource 2 is not a limiting factor, but could become one in the event an increase in either resource 9 or, definitely, resource 4 occurred on the associated eminating network branch.

This analysis is further supported through the server utilization data (Table III). These values describe the percent of time that a specific GSS process is being utilized. A process in use a large percentage of the time emphasizes that the flow through this process is adequate. Conversely, if the process is used very little this indicates a constraint somewhere prior to this specific process. The latter situation has occurred with regard to the SRB subsystem. The SRB processing activity, server/activity 14, within the SRSF, is in use a moderate 41% of the time indicating that the flow through the system, prior to this point, is adequate. The SRB stacking process, server/activity 15, is, however, only in use approximately

20% of the time indicating a reduction in flow due to the launch pad resource. This data also shows low server utilization for the shipping process, server/activity 13, approximately 16%, from KSC to VAFB; again, indicating a possible problem in this area if the launch pad resource was increased in the future.

In summary, through an analysis of the data provided by the Q-GERT Analysis Program, in conjunction with the Q-GERT network diagram of the VAFB GSS, possible constraints and limiting factors were identified. The identification of these areas, and discussions with AFOTEC personnel (10,23), resulted in the selection of appropriate variables for use in the sensitivity analysis discussed in the next subsection. This analysis was performed with the VAFB GSS configuration, as described in Chapter II, as the baseline.

Sensitivity Analysis.

After thoroughly analyzing the model and discussing its operation with AFOTEC personnel, six variables of interest were identified:

1. the useful life of the SRM segments in terms of number of launches experienced (LIFE),
2. the SRM production rate at Thiokol in days (SRM),
3. the ET production rate at Michoud in days (ET),
4. refurbishment of forward and aft skirts requiring transportation to and from KSC, or refurbishment at VAFB, in terms of yes and no ('Y'and 'N'),

5. number of orbiters available (ORB), and
6. number of shifts worked, with 2 corresponding to 16 hour days, five days per week, and 3 denoting 24 hour days, seven days per week (SHIFT).

TABLE IV

Sensitivity Analysis
Variable Values & Levels

	LIFE	SRM	ET	XPT	ORB	SHIFT
		3650				
		730	180			
		365	150			
		270	120			
	100	210	90			
* BASELINE	20	150	60	'Y'	1	2 *
	5	30	30	'N'	2	3
	3	15	15		3	
	2		10		4	
					5	

The baseline values for each of these variables were determined from analysis, discussion and a telephone interview with Marshall Space Flight Center (MSFC) personnel. The ET production rate baseline was determined by pro-rating. With production currently scheduled at 24 per year, each of the four orbiters can be allotted six ETs. Since one

orbiter is dedicated to VAFB, assigning six ETs per year to VAFB translates into approximately one ET produced every 60 days. The number of useful SRM segment lives was placed at 20 by AFOTEC personnel (10). Information regarding SRM production was obtained from a combination of two documents on file at MSFC entitled NASA Program Operating Plan 84-2 and the Flight Determination Requirements Directive (4). These documents indicated an average production rate of 2.5 SRB sets per year, or about one every 150 days. The baseline values, along with the full range of values for each variable, are depicted in Table IV. In addition, it is easy to see that there are five values associated with the variables LIFE and ORB, eight values for SRM and ET, and two values for XPT and SHIFT. The number of values for each variable are referred to as levels and will be addressed later in this analysis. After determining the variables of interest and the appropriate baseline, sensitivity analysis was performed.

A univariate analysis was conducted by running the Q-GERT program at each level of one variable while holding the others constant at the baseline. This data produced 25 combinations (cases), resulting in 25 different times between launches (TBLs) (see Appendix D). Using the Final Results for 10 Simulations, the TBLs were recorded for each of the 25 cases. The results were very similar with few exceptions. Although the TBLs ranged between 71.8843 and

177.7102, twenty of the first 25 cases were within 0.6 days of one another at just over 105. These TBLs are translated into average annual launch rates by dividing them into 365 days. The variable SHIFT yielded the lowest TBL, resulting in the highest average annual launch rate at 5.08 launches per year. The next highest launch rates were represented by the clustered group of 20 cases. These were primarily composed of the univariate results from the variables LIFE, SRM, XPT, and ORB, yielding between 3.45 and 3.47 launches per year. The only exception occurred when LIFE was decreased to two uses resulting in a reduced rate of 2.86 average launches per year. At the far end of the scale, the ET production rate, when increased above 90 days (or less than four ETs per year), reduced the average launch rate to a minimum of 2.05 per year. This reduction is easy to understand since the TBLs were almost identical with the respective production rates used. It makes sense that ETs can only be launched as fast as they're produced.

Due to the clarity of the results and the robustness of the univariate analysis, further sensitivity was deemed unnecessary. However, a limited multivariate analysis was performed to capitalize on what was observed to be the most significant variables and to determine a maximum launch rate to test the capability of the system. Ten additional cases were run through the Q-GERT model to accomplish this objective. The data for these cases, including the

accompanying TBLs, is listed as the last 10 cases in Appendix D. Between two and five variables were changed simultaneously and the results recorded. The lowest TBL corresponding to the highest average annual launch rate was observed when the variables XPT, ORB, SHIFT, and ET were changed from the baseline to reflect: no transportation to KSC, two or more orbiters, three shifts and an ET production rate which allowed at least as many ETs to be produced per year as launches. The results were identical for all of the 4 factor cases described above, with the TBLs equal to 50.3710, corresponding to an average of 7.25 launches per year. Again, the findings were clear, however to corroborate them, further analysis was performed.

Analysis of Variance. Using the SPSS program for Analysis of Variance (ANOVA), higher order interactions were analyzed to determine the statistically significant variables. In addition, means and variances were compared using a ONEWAY or single factor design. Because ANOVA is limited to five factor designs, only five of the six variables were used in the fixed model at one time. The minimum number of cells that would be generated with five variables, considering their levels, would be 800 (8x5x5x2x2=800). To generate the necessary data from the Q-GERT model to fill these cells would not only be beyond the scope of this research, but would also require an enormous amount of computer time. Consequently, only the results of the univariate and limited multivariate analysis were used.

The purpose of this analysis was to determine which of the controllable factors (independent variables), is the most influential in achieving the average annual launch rate. Initially, two different 5 factor fixed models (see Appendix E) were run with the limited data described above. (All SPSS analyses were performed using a probability of 0.95 or an alpha equal to 0.05.) The null hypotheses for each model state that the launch rates are equal for each level of its respective variable while the alternate hypotheses state they are not equal. If the F probability of the ANOVA is less than the 0.05 alpha value, then that variable is statistically significant. The results of the 5 factor ANOVA in both models show SHIFT to be significant (0.001<0.05) while the decision is to fail to reject the null hypotheses for the remaining variables since all had probabilities greater than 0.05.

Because the limited data produced some empty cells and singular matrices in the 5 factor models, higher order interactions were suppressed. As a result, ONEWAY analyses were run for further clarification of the results (see Appendix F). Each of the six variables was run separately against the dependent variable, launch rate (LRATE), to determine whether any of the other variables were significant when changed by themselves. The results of the ONEWAY analyses on the original 25 cases again revealed SHIFT to be the only significant variable (0.0<0.05). An

additional ONEWAY analysis of SHIFT for all 35 cases also showed a significant difference between using two and three shifts (0.0<0.05).

The Duncan and Tukey Range tests were also used to analyze SHIFT (see Appendix G) and supported the results of the ANOVA and ONEWAY analyses by breaking out the shifts in different subsets demonstrating that they were significantly different. The results of the Range tests for all 35 cases revealed an average LRATE of 3.33 for two shifts and 6.39 for three shifts. Although SHIFT is the only statistically significant variable in the six variable launch rate equation, a combination of variable changes in the Q-GERT model, such as the 4 factor multivariate analysis described earlier, can obviously have a significant impact on the average annual launch rate.

The previous subsections have presented a thorough description of the major results of the Q-GERT model and sensitivity analysis, as applicable to the objectives and scope of this research. The next subsection capsulizes these results for easy reference.

Summary of Results

The analysis of the Q-GERT model of the VAFB GSS resulted in the determination of the yearly launch rate for this specific GSS configuration and the identification of bottlenecks/constraints within the proposed system. The baseline GSS launch rate was determined to be 3.4577

launches per year, with a minimum of 3.4365 and a maximum of 3.47 launches per year. The proximity of these figures indicates the reliability of the model and a consistency in application of the basic assumptions discussed in Chapter III. The Launch Pad capacity was identified as the major bottleneck and the SRB subsystem as the primary constraining area within the Ground Support System. An increase in LP capacity would require corresponding increases in the SRSF capacity and/or an increase in the availability of railroad cars to transport the refurbished forward and aft skirt assemblies from KSC to VAFB.

Six specific variables of interest were determined from this initial analysis for use in the sensitivity analysis. The sensitivity analysis identified SHIFT as the only statistically significant variable. Through a univariate analysis, the maximization of work shifts (3 shifts/24 hours per day/seven days a week), resulted in a possible launch rate of 5.08 launches per year. The utilization of a multivariate analysis, which maximized the variable values for SHIFT, ORB, XPT, and ET, resulted in the achievement of 7.25 launches per year. This launch rate is the maximum attainable utilizing the currently proposed VAFB GSS configuration as modified by Activation Optimization.

This chapter presented the results/output of the Q-GERT simulation model of the VAFB GSS as modified by AO. Six specific variables were chosen from these results and a

sensitivity analysis performed on the model using these variables. The significance of the output and the sensitivity analysis results, as well as, recommendaions for further research efforts will be addressed in Chapter V.

V. Conclusions, Implications, and Recommendations

The Space Transportation System has been identified and directed by National Space Policy that it be the primary method for launching NASA, DOD, and commercial payloads into orbit for the remainder of this century and beyond. In order to fulfill this mission two sites have been selected for launching the Space Shuttle Vehicle: the John F. Kennedy Space Center and Vandenberg AFB. The STS operations at KSC have been fully functional for three years with 11 successful missions to its credit. The Vandenberg Launch Site is currently under construction with an IOC of October 1985, and full operational capability is scheduled for July 1987.

Initially the VLS was to be similar to that of KSC with all facilities and resources necessary to refurbish the reuseable components of the SSV. However, a joint NASA/DOD study in 1981/82, called Activation Optimization, identified certain refurbishment processes and functions that could be accomplished more economically at KSC and resulted in the complete or partial deletion of several facilities at VAFB, as discussed in Chapter I.

The purpose of this research was, therefore, to determine specifically what impact the changes to the GSS, implemented by AO, would have on the SSV ground turnaround times and consequently on the annual launch rate from the VLS.

Once the problem was identified, the specific objective of this research was determined and several research questions formulated (see Chapter I) to guide the direction of the research toward this objective. In order to adequately address these questions and meet the objective a simulation approach was judged to be the best method to analyze the VAFB GSS performance. Q-GERT was chosen as the simulation language, discussed in Chapter II, and a model was developed of the VAFB GSS, as modified by AO, and is fully described in Chapter III.

The data utilized in the formulation and execution of the model was obtained from VSTAR 10, the most current data available at this time. However, since the VAFB GSS is not presently operational, this data is based on information obtained from KSC operations and modified for the VLS.

Conclusions

Research questions 1, 2, and 4 were addressed throughout Chapter III and provided the foundation for the procedures utilized in the formulation of the VAFB GSS model. The completed and validated model then provided the answers to research questions 3, 5, and 6. These results are conclusively addressed in Chapter IV.

The analysis of the model output, as described in Chapter IV, resulted in the identification of the Launch Pad capacity at VAFB as a major bottleneck in the VAFB GSS system. Also identified as possible future constraints in

the system were the SRSF capacity and the railroad car resource associated with the transportation of the refurbished forward and aft skirt assemblies from KSC to VAFB. Finally, the operational model produced the resolution of the overall objective of this research, the time between launches of the SSV leading to specification of the annual launch rate for the VLS.

There are several implications which stem from the analysis of the model results. First, the amount of time/number of shifts worked has an impact on the annual launch rate. The work rate of two shifts/16 hours per day/five days per week resulted in a launch rate of 3.4577 launches per year, while a rate of three shifts/24 hours per day/seven days per week resulted in a launch rate of 5.08 launches per year. These values imply that the present VAFB GSS, as modified by AO, can meet the Program Management Directive (PMD) requirements of four launches per year with a surge capability to 5 launches per year utilizing a work schedule rate somewhere between the two listed above. Second, since the maximum attainable launch rate for the system is only 7.25 launches per year (see Chapter IV), it cannot currently meet the PMD requirement for expansion to ten launches per year. The only way to increase the VLS launch capacity would be to increase some, if not all, of the facilities and resources associated with the VAFB GSS. A complete analysis of this particular aspect is not within

the scope of this research. However, the analysis did indicate the launch pad as the primary constraint on the system. If this resource were to be expanded, at some future date, then the analysis signified a corresponding increase would probably be necessary in the SRSF capacity and in the number of railroad cars available for transport of the refurbished SRB components from KSC to VAFB. The latter constraint could additionally lead to the expansion of the SRSF facilities to accomplish all refurbishment of the SRBs at VAFB as an alternative measure. These are definitely strong areas for further research, as well as, determination of other options to substantially increase the VLS launch rate, should the necessity arise.

Recommendations

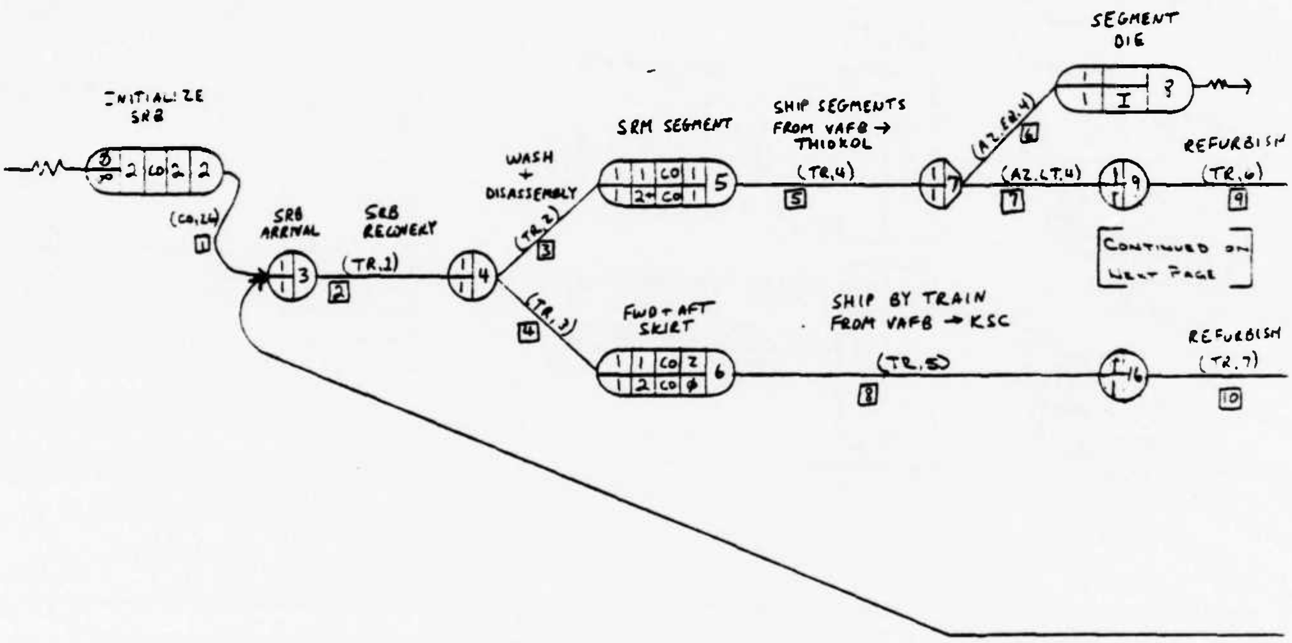
Initially, as more data becomes available, especially after STS operations commence at the Vandenberg Launch Site, a re-evaluation and subsequent update of the model assumptions and assessed time values (GSS processing times) is necessary to insure timely and accurate model output. Along the same lines, as the VLS becomes fully operational, a comparison of the model with the "real world" system, in conjunction with new data and updated assumptions, is essential to further enhance the reliability and test the external validity of the model.

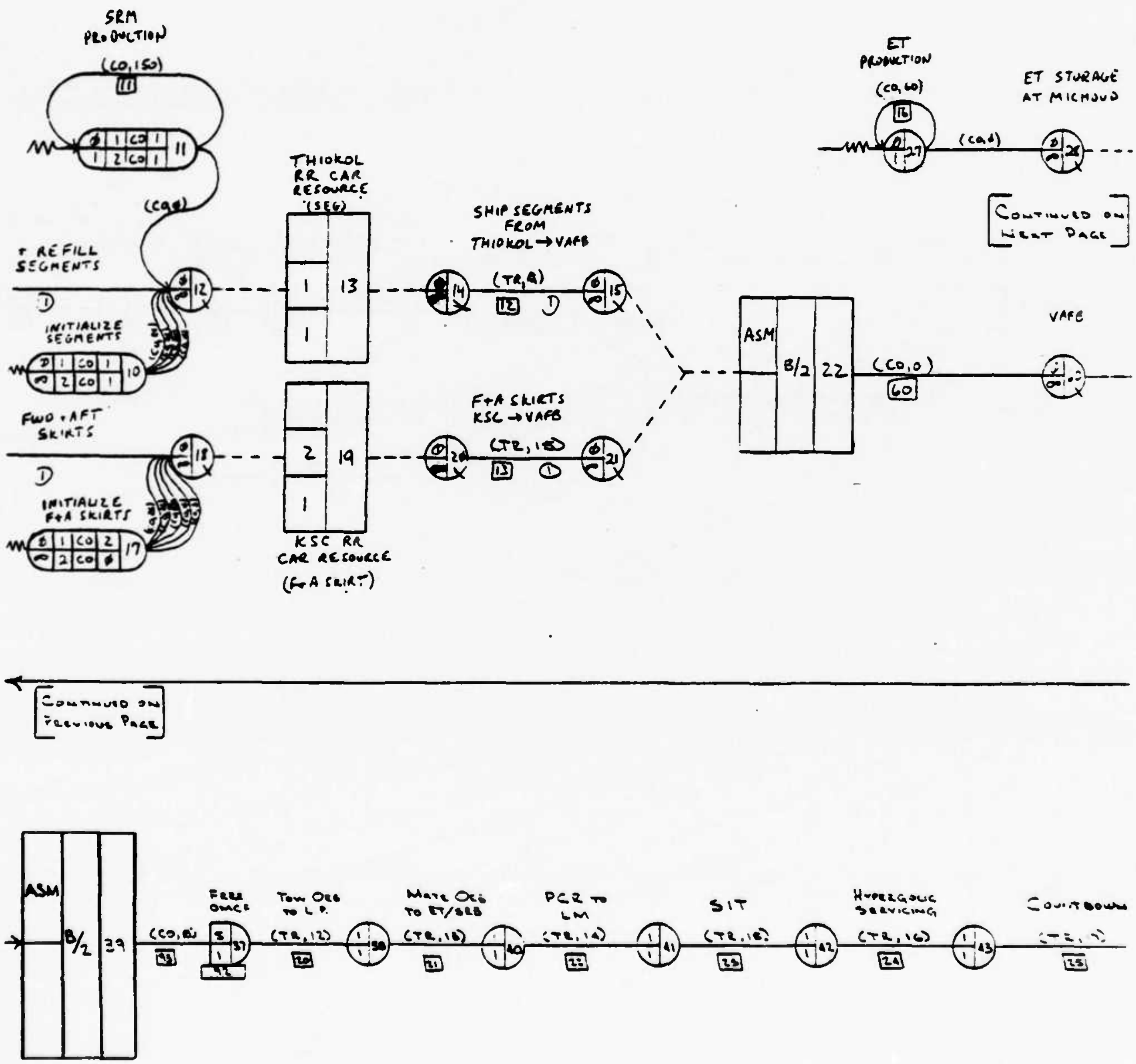
As previously indicated in this chapter, further research is needed to study the impact of GSS facility and

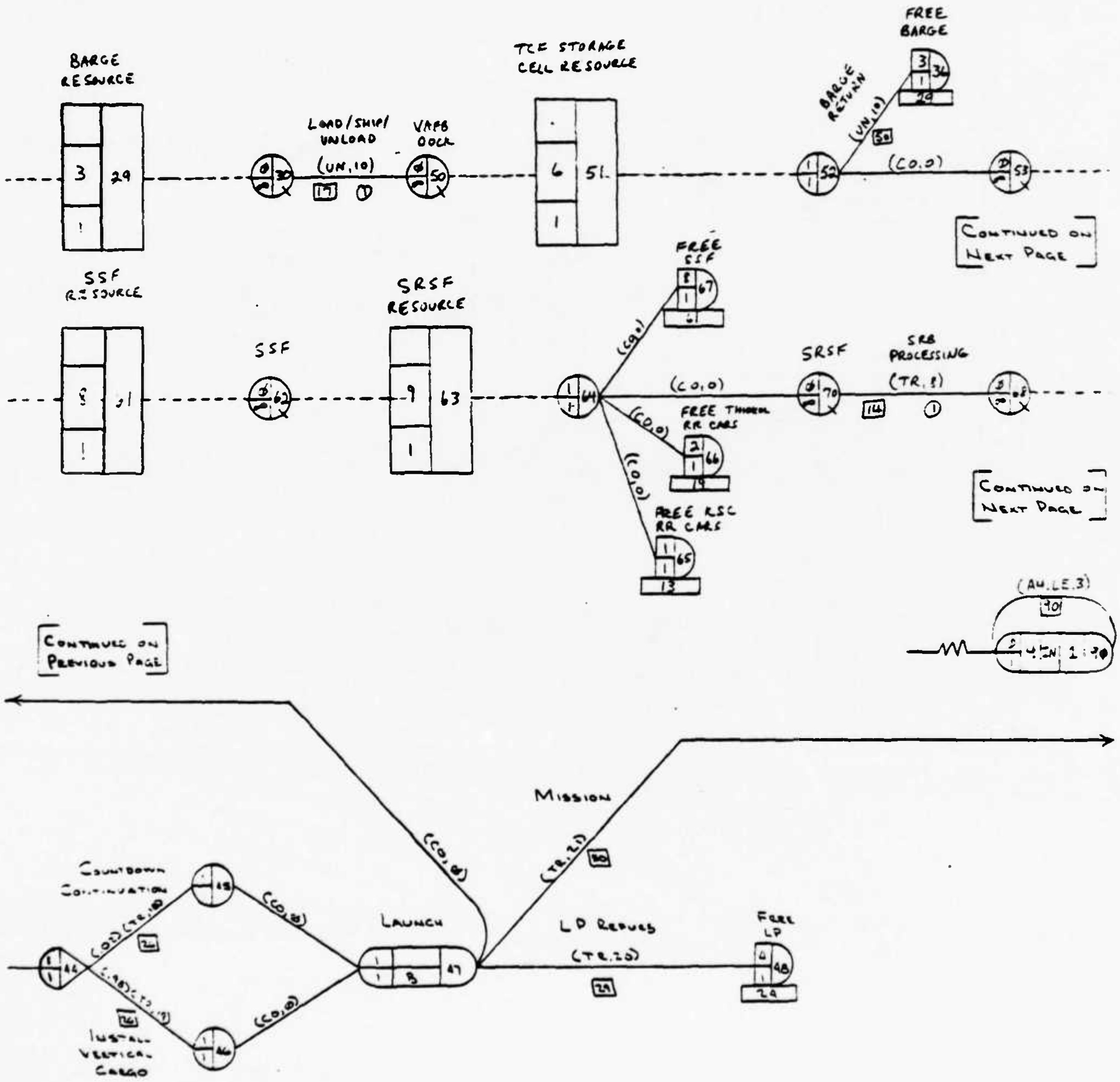
resource expansion in an effort to increase the VLS launch rate. Another aspect recommended for further research would be to address and compare several different VAFB Ground Support System configurations to determine the most cost effective/efficient combination of facilities and resources.

This chapter has summarized the National Space Policy effort with regard to the Space Transportation System in general, specifically addressing the STS operations at Vandenberg AFB. The conclusions drawn from the results of the model of the VAFB GSS produced significant implications concerning the current GSS configuration. This analysis also established specific recommendations for continued research in other aspects of the VAFB Ground Support System which may have a significant impact on the future Space Transportation System operations at the Vandenberg AFB Launch Site.

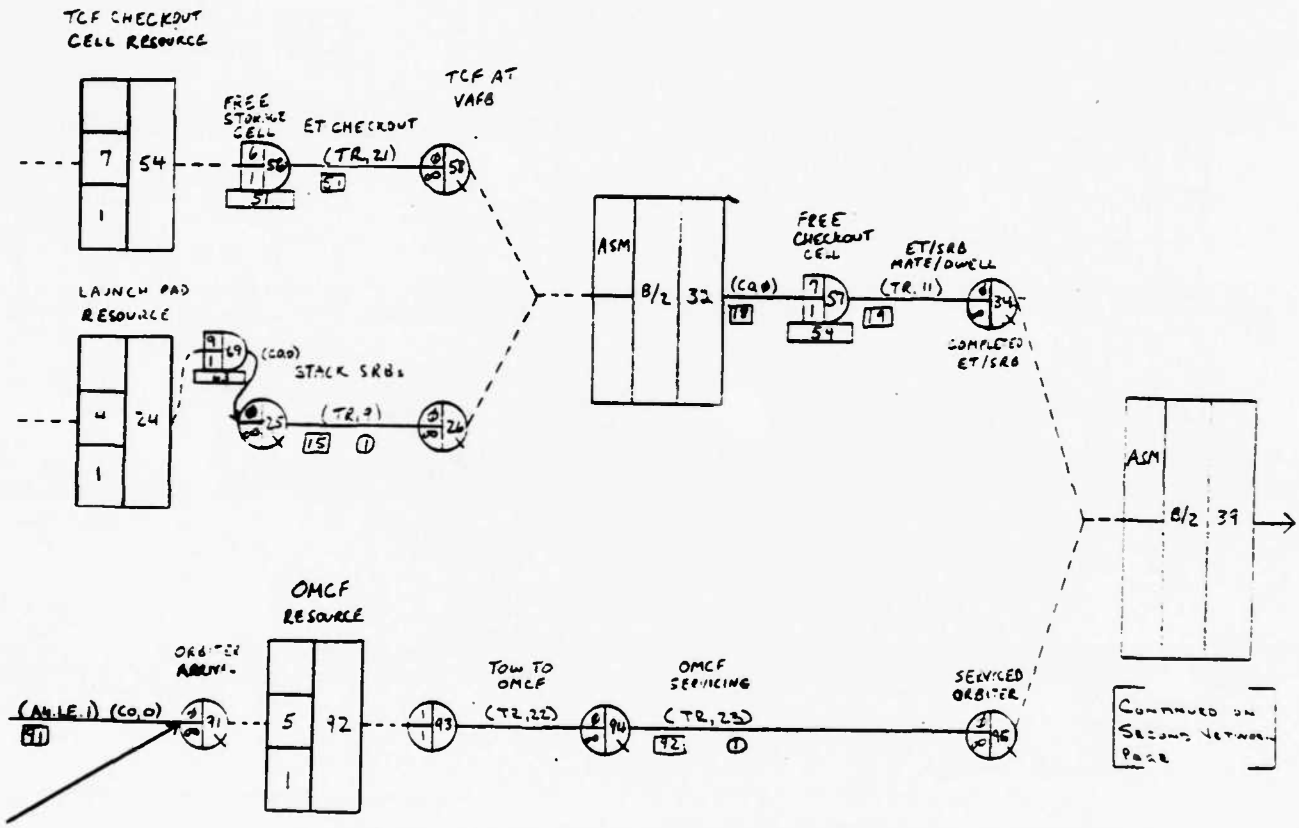
Appendix A. Q-GERT Network Model




SRM PRODUCTION
ET PRODUCTION
ET STORAGE AT MICHOUD
THIOKOL RR CAR RESOURCE (SEG)
SHIP SEGMENTS FROM THIOKOL → VAFB
REFILL SEGMENTS
INITIALIZE SEGMENTS
FWD + AFT SKIRTS
INITIALIZE F+A SKIRTS
F+A SKIRTS KSC → VAFB
KSC RR CAR RESOURCE (F+A SKIRT)
VAFB
ASM
Continued on Next Page
Continued on Previous Page
Free Dock
Tow Orb to L.P.
Mate Orb to ET/SRB
PCR to LM
SIT
Hypergolic Servicing
Countdown



BARGE RESOURCE
LOAD/SHIP/UNLOAD
(UN,10)
VAFB DOCK
TCF STORAGE CELL RESOURCE
BARGE RETURN
(UN,10)
FREE BARGE
(CO,0)
Continued on Next Page
SSF RESOURCE
SSF
SRSF RESOURCE
FREE SSF
(CO,0)
SRSF
SRB PROCESSING
(TR,8)
FREE THIOKOL RR CARS
FREE KSC RR CARS
Continued on Next Page
(AU,LE,3)
Continues on Previous Page
Mission
Countdown Continuation
Launch
LP Refurb
(TR,20)
Free LP
Install Vertical Cargo


TCF CHECKOUT CELL RESOURCE
FREE STORAGE CELL
ET CHECKOUT
(TR,21)
TCF AT VAFB
LAUNCH PAD RESOURCE
STACK SRBs
(TR,7)
ASM
B/2
FREE CHECKOUT CELL
ET/SRB MATE/DWELL
(TR,11)
COMPLETED ET/SRB
OMCF RESOURCE
TOW TO OMCF
(TR,22)
OMCF SERVICING
(TR,23)
SERVICED ORBITER
Continued on Second Network Page

Appendix B. Q-GERT Computer Program

```
***********************************************************************
*  THIS PROGRAM REPRESENTS THE COMPUTERIZATION OF THE Q-GERT          *
*  NETWORK MODEL DESIGNED TO SIMULATE THE VAFB GROUND SUPPORT         *
*  SYSTEM (GSS).  THE PROGRAM PERFORMS 10 RUNS OF THE MODEL           *
*  WITH EACH RUN BEING 10 YEARS OR 3650 DAYS LONG.  THE OUTPUT        *
*  REPRESENTS THE FINAL RESULTS OF 10 SIMULATIONS AVERAGED            *
*  TOGETHER.                                                          *
***********************************************************************
*
*
*     GENERAL PROJECT AND NETWORK DATA
*
GEN,BENBUD,VAFBGSS,8,5,1984,1,1,9999,3650,10,S,26,4*
*
***********************************************************************
*  THIS SECTION PROVIDES GENERAL INFORMATION REGARDING                *
*  RESOURCES.  THE THIRD FIELD INDICATES THE NUMBER OF UNITS OF       *
*  THE RESOURCE TYPE THAT ARE AVAILABLE AT THE BEGINNING OF           *
*  EACH RUN (INITIAL RESOURCE CAPACITY).                              *
***********************************************************************
*
*     RESOURCE TYPE DEFINITION
*
RES,1/SEGS,1,13*                      RR CARS (THIOKOL)
RES,2/SKIRTS,1,19*                    RR CARS (KSC)
RES,3/BARGE,4,29*                     ET BARGES
RES,4/LP,1,24*                        LAUNCH PADS
RES,5/OMCF,1,32*                      ORBITER MX FACILITIES
RES,6/ETSC,4,51*                      ET STORAGE CELLS
RES,7/ETCO,1,54*                      ET CHECKOUT CELLS
RES,8/SRB STOR,1,41*                  SRB STORAGE CELLS
RES,9/SRSF,2,53*                      SRB SERVICE FACILITY BAYS
*
***********************************************************************
*  THIS SECTION DEPICTS THE VALUES ASSIGNED TO SELECTED               *
*  ATTRIBUTES.  THE THREE REQUIRED ITEMS OF INFORMATION SHOWN         *
*  IN FIELDS 3,4, AND 5 ARE: ATTRIBUTE NUMBER, FUNCTION TYPE,         *
*  AND THE PARAMETER IDENTIFIER.  SUCCESSIVE FIELDS REPEAT            *
*  THIS PATTERN.                                                      *
***********************************************************************
*
*     VALUE ASSIGNMENT TO ATTRIBUTES
*
VAS,2,2,CO,2*                         SRB PAIR
VAS,5,1,CO,1,2,CO,1*                  SRM SEGMENTS
VAS,6,1,CO,2,2,CO,0*                  FWD & AFT SKIRTS
VAS,10,1,CO,1,2,CO,1*                 SRM SEGMENTS
VAS,11,1,CO,1,2,CO,1*                 NEW SRM SEGMENTS
VAS,17,1,CO,2,2,CO,2*                 FWD & AFT SKIRTS
VAS,90,4,IN,1*                        INCREMENT ORBITERS
*
```

```
*****************************************************************
*  THIS SECTION SPECIFIES THE OPERATING INSTRUCTIONS FOR SOURCE *
*  NODES, WHICH GENERATE INITIAL TRANSACTIONS.                  *
*****************************************************************
*
*     SOURCE NODE DESCRIPTION
*
SOU,2,0*                                INITIALIZE SRB PAIR
SOU,10,0*                               INITIALIZE SRM SEGMENTS
SOU,11,0,1*                             SRM PRODUCTION (THIOKOL)
SOU,17,0*                               INITIALIZE FWD & AFT SKIRTS
SOU,27,0,1*                             ET PRODUCTION (MICHOUD)
SOU,90,0,1,A*                           INITIALIZE ORBITERS
*
*****************************************************************
*  THIS SECTION SPECIFIES THE CONDITIONS WHICH END THE PROCESS- *
*  ING OF TRANSACTIONS; IN THIS CASE, SRM SEGMENT TRANSACTIONS  *
*  THAT HAVE EXCEEDED THEIR USEFUL LIFE TERMINATE.              *
*****************************************************************
*
*     SINK NODE DESCRIPTION
*
SIN,8/SRM DIE,1,1,,I*                   SRM SEGMENTS DIE
*
*****************************************************************
*  THIS SECTION DESCRIBES THE TYPE OF STATISTICS TO BE MAIN-    *
*  TAINED; IN THIS CASE, THE TRANSACTION FLOW TIME BETWEEN      *
*  LAUNCHES.  THE OUTPUT IS THE BASIS FOR THE LAUNCH RATE.      *
*****************************************************************
*
*     STATISTICS NODE DESCRIPTION
*
STA,47/LAUNCH,,1,,B*                    TIME BETWEEN LAUNCHES (TBL)
*
*****************************************************************
*  THIS SECTION DEFINES THE NODES USED TO ALLOCATE RESOURCES TO *
*  TRANSACTIONS WHEN THE RESOURCES BECOME AVAILABLE DUE TO A    *
*  TRANSACTION PASSING THROUGH A FREE NODE.  FIELD 4 REFERS TO  *
*  THE RESOURCE TYPE DEFINED EARLIER.                           *
*****************************************************************
*
*     ALLOCATE NODE DEFINITION
*
ALL,13,,1,1,12/14*
ALL,19,,2,1,18/20*
ALL,29,,3,1,29/30*
ALL,24,,4,1,68/69*
ALL,92,,5,1,91/93*
ALL,51,,6,1,50/52*
ALL,54,,7,1,53/55*
ALL,61,,8,1,60/62*
ALL,63,,9,1,62/64*
*
```

```
*****************************************************************
*  THIS SECTION GIVES THE INFORMATION THAT ALLOWS TRANSACTIONS  *
*  TO MAKE RESOURCES AVAILABLE.  THE FOURTH FIELD INDICATES THE *
*  RESOURCE TYPE TO BE FREED.                                   *
*****************************************************************
*
*     FREE NODE DEFINITION
*
FRE,65,,1,1,13*
FRE,66,,2,1,19*
FRE,36,,3,1,29*
FRE,48,,4,1,24*
FRE,37,,5,1,92*
FRE,56,,6,1,51*
FRE,57,,7,1,54*
FRE,67,,8,1,61*
FRE,69,,9,1,63*
*
*****************************************************************
*  THIS SECTION DEFINES A TYPE OF SELECTION PROCEDURE INVOLVING *
*  CHOICES BETWEEN SEVERAL QUEUE NODES OR SERVERS.  THE QUEUE   *
*  SELECTION PROCEDURE USED EXCLUSIVELY HERE IS ASSEMBLY MODE   *
*  SELECTION (ASM), WHICH PROVIDES A MEANS FOR MERGING TRANS-   *
*  ACTIONS FROM 2 QUEUES.  FIELD 5 SPECIFIES THE CRITERION BY   *
*  WHICH AN ATTRIBUTE CAN BE MAINTAINED AFTER THE TRANSACTIONS  *
*  ARE ASSEMBLED.  CRITERION B/2 REQUIRES THE BIGGEST VALUE OF  *
*  ATTRIBUTE 2 (COUNTS SEGMENT LIVES) TO BE MAINTAINED.         *
*****************************************************************
*
*     SELECTOR NODE DESCRIPTION
*
SEL,22/SEG F&A,ASM,,B/2,,15,21*     SEG/F&A SKIRTS ARRIVE VAFB
SEL,32/ET SRB,ASM,,B/2,,58,26*      ET/SRB MATE
SEL,39/ORB ET,ASM,,B/2,,34,55*      ORBITER/ET MATE
*
```

```
*****************************************************************
*  THIS SECTION DESCRIBES NODES WHICH HAVE NO SPECIAL FUNCTION  *
*  OTHER THAN RECEIVING AND ROUTING TRANSACTIONS.               *
*****************************************************************
*
*     REGULAR NODE DESCRIPTION
*
REG,3,1,1*                               SRB ARRIVAL
REG,4,1,1*
REG,5,1,1,D*
REG,6,1,1*
REG,7,1,1,F*
REG,9,1,1*
REG,16,1,1*
REG,38,,1*
REG,40,,1*
REG,41,,1*
REG,42,,1*
REG,43,,1*
REG,44,,1,P*
REG,45,,1*
REG,46,,1*
REG,52,,1*
REG,64,,1*
REG,93,,1*
*
*****************************************************************
*  THIS SECTION LISTS NODES AT WHICH TRANSACTIONS MAY WAIT FOR  *
*  SERVICE ACTIVITIES.  IN ADDITION, STATISTICS ARE AUTOMATIC-  *
*  ALLY COLLECTED ON Q-NODES.                                   *
*****************************************************************
*
*     QUEUE NODE DESCRIPTION
*
QUE,12/RR,(10)13*                        THICKOL RAILHEAD
QUE,14*
QUE,15/SEG,(10)22*                       SEGS WAIT FOR F&A SKIRT
QUE,18/RR,(10)19*                        KSC RAILHEAD
QUE,20*
QUE,21/F&A,(10)22*                       F&A SKIRTS WAIT FOR SEGS
QUE,25/STRT STK*                         SRBS AWAIT STACKING
QUE,29/MICHOUD,(10)29*                   ET STORAGE AT MICHOUD
QUE,30*
QUE,58/TCF,(10)32*                       ET AWAITS STACKED SRBS
QUE,26/STACKED,,(10)32*                  STACKED SRBS AWAIT ET
QUE,34/ET SRB,(10)39*                    ET/SRB AWAITS ORBITER
QUE,50/VAFBDOCK,(10)51*                  ETS AWAIT TCF STORAGE
QUE,53/ET STORE,(10)54*                  ETS AWAIT TCF CHECKOUT CELL
QUE,60,(10)61*                           SRBS AWAIT STORAGE
QUE,62/SRB STOR,(10)63*                  SRBS AWAIT SRSF ENTRY
QUE,68/PRE STAK,(10)24*                  SRBS AWAIT LAUNCH PAD
QUE,70/SRSF*                             SRBS AWAIT PROCESSING
QUE,91/ORB ARR,(10)92*                   ORBITER RETURN
QUE,94/OMCF*                             ORBITER AWAITS SERVICING
QUE,95/ORBITER,(10)39*                   ORBITER AWAITS ET/SRB MATE
*
```

```
****************************************************************
*  THIS SECTION PROVIDES INFORMATION REGARDING THE ROUTING OF   *
*  TRANSACTIONS INCLUDING THE DURATION OF THE ACTIVITY.  FIELDS *
*  4 AND 5 DEFINE THE DISTRIBUTION OR FUNCTION TYPE AND THE     *
*  PARAMETER SET OR CONSTANT, RESPECTIVELY.                     *
****************************************************************
*
*     ACTIVITY DESCRIPTION
*
ACT,3,4,TR,1,2/SRB REC*                 SRB RECOVERY
ACT,4,5,TR,2,3/SRM DIS*                 SRM DISASSEMBLY
ACT,4,6,TR,3,4/F&A DIS*                 FWD & AFT SKIRT DISASSEMBLY
ACT,5,7,TR,4,5/SEG XPT*                 TRANSPORT SEG TO THIOKOL
ACT,14,15,TR,4,12/SEG XPT*              TRANSPORT SEG TO VAFB
ACT,9,12,TR,6,9/SEG R&R*                SEG REFURB & REFILL
ACT,16,18,TR,7,10/F&A R&R,1*            F & A SKIRT REFURB & REFILL
ACT,70,68,TR,8,10/SRB PROC,1*           SRB PROCESSING
ACT,25,26,TR,9,15/SRB STAK*             STACK SRBS ON LP
ACT,30,50,UN,10,17/BARGE*               TRANSPORT ETS TO VAFB
ACT,52,36,UN,10,50*                     RETURN BARGE TO MICHOUD
ACT,57,34,TR,11,19*                     ET/SRB MATE/DWELL
ACT,37,38,TR,12,20*                     TOW ORBITER TO LP
ACT,38,40,TR,13,21/ORB MATE*            ORBITER/ET/SRB MATE
ACT,40,41,TR,14,22*                     PCR TO LAUNCH MODULE
ACT,41,42,TR,15,23*                     SSV INTEGRATION TEST
ACT,42,43,TR,16,24*                     HYPERGOLIC SERVICING
ACT,43,44,TR,17,25*                     INITIAL COUNTDOWN OPS
ACT,44,45,TR,18,26,,.02*                FINAL COUNTDOWN OPS
ACT,44,45,TR,19,26,,.98*                INSTALL VERTICAL PAYLOAD
ACT,47,48,TR,20,29*                     LAUNCH PAD REFURB
ACT,47,91,TR,21,30/MISSION*             ROUTE TO ORBITER SUBSYSTEM
ACT,56,53,TR,21,51*                     ET CHECKOUT
ACT,93,94,TR,22/TOW*                    TOW ORBITER TO OMCF
ACT,94,95,TR,23,92/OMCF*                OMCF SERVICING
```

```
ACT,2,3.CO,26,1/INIT SRB*          INITIALIZATION TIME DELAY
ACT,10,12*                         INITIALIZE SEG AT RAILHEAD
ACT,10,12,CO,26*                   INITIALIZATION TIME DELAY
ACT,10,12,CO,26*                   INITIALIZATION TIME DELAY
ACT,10,12,CO,26*                   INITIALIZATION TIME DELAY
ACT,11,12*                         NEW SEGMENTS TO RAILHEAD
ACT,17,18,CO,26*                   INITIALIZATION TIME DELAY
ACT,17,18,CO,26*                   INITIALIZATION TIME DELAY
ACT,17,18,CO,26*                   INITIALIZATION TIME DELAY
ACT,17,18*                         INITIALIZE SKIRT AT RAILHEAD
ACT,17,18*                         INITIALIZE SKIRT AT RAILHEAD
ACT,22,60,,,60*
ACT,27,28*
ACT,32,57,(6)18*
ACT,39,37,(6)93*
ACT,45,47*
ACT,46,47*
ACT,47,3/SRB*                      ROUTE TO SRB SUBSYSTEM
ACT,52,53*
ACT,64,65*
ACT,64,66*
ACT,64,67*
ACT,64,70*
ACT,69,23*
ACT,90,90,,,90/ORB GEN,,1,A4.LE.3* ORBITER GENERATOR
*
*******************************************************************
*  THIS SECTION PROVIDES A CONVENIENT FORMAT FOR CONDUCTING       *
*  SENSITIVITY ANALYSIS.  DESIRED CHANGES CAN BE QUICKLY AND      *
*  EASILY MADE TO 5 OF THE 6 VARIABLES IN THE LAUNCH RATE         *
*  EQUATION ADDRESSED IN CHAPTER IV:  LIFE, SRM, ET, XPT, AND     *
*  ORB.  TO CHANGE THE VALUES OF THESE VARIABLES, SIMPLY MAKE     *
*  THE DESIRED CHANGE WHERE INDICATED BY A QUESTION MARK BELOW    *
*  THE VALUE.                                                     *
*******************************************************************
*                     SENSITIVITY ANALYSIS                        *
*******************************************************************
ACT,7,8,,,6/SRM DIE,,1,A2.EQ.20*   SRM DIE PATH
***                          ??
ACT,7,9,,,7/SRM LIVE,,2,A2.LT.20*  SRM NORMAL PATH
***                           ??
ACT,11,11,CO,150,11/SRM PROD*      SRM PRODUCTION RATE=2.4/YEAR
***        ?? ???                                      ???
ACT,27,27,CO,60,16/ET PROD*        ET PRODUCTION RATE=6/YEAR
***        ?? ??                                      ?
ACT,6,16,TR,5,8/TRAIN*             TRANSPORT SKIRTS TO KSC
***       ?? ?
ACT,20,21,TR,5,13/TRAIN*           RETURN SKIRTS TO VAFB
***        ?? ?
ACT,90,91,,,91/ORBS,,2,A4.LE.1*    1 ORBITER(S) IN USE
***                          ?     ?
```

```
*****************************************************************
*  THE FINAL SECTION LISTS THE PARAMETER SETS BY NUMBER IN      *
*  FIELD 2 CORRESPONDING TO THE PARAMETER IDENTIFIER IN FIELD 5 *
*  OF THE ACTIVITY CARDS.  THESE PARAMETER SETS ARE ASSOCIATED  *
*  WITH SPECIFIC FUNCTION TYPES AS DEFINED IN FIELD 4 OF THE    *
*  ACTIVITY CARDS.  ALL PARAMETERS HERE DEFINE TRIANGULAR DIS-  *
*  TRIBUTIONS, EXCEPT SET 10 WHICH IS A UNIFORM DISTRIBUTION,   *
*  AND ALL UNITS ARE IN DAYS.                                   *
*       THIS ENTIRE SECTION COMPRISES THE VARIABLE, SHIFT, AS   *
*  DEFINED IN CHAPTER IV.  IN ORDER TO CONDUCT SENSITIVITY      *
*  ANALYSIS ON THIS VARIABLE, IT IS NECESSARY TO REPLACE THE    *
*  VALUES OF 15 PARAMETER SETS:  SET NUMBERS 2-3, 6-9, 11, AND  *
*  13-20.  THESE VALUES ARE IN TERMS OF 2 SHIFTS (16 HOUR DAYS, *
*  5 DAYS PER WEEK) AND MUST BE CONVERTED TO 3 SHIFTS (24 HOUR  *
*  DAYS, 7 DAYS PER WEEK).  A CONVERSION FACTOR OF 0.476 IS     *
*  OBTAINED BY DIVIDING AN 80 HOUR WEEK BY A 168 HOUR WEEK.     *
*  EACH 2 SHIFT VALUE, WHEN MULTIPLIED BY THE CONVERSION FACTOR *
*  WILL YIELD A 3 SHIFT VALUE.  THESE VALUES ARE LISTED IN A    *
*  SEPARATE TABLE FOR CONVENIENCE.                              *
*****************************************************************
*
*     PARAMETER DATA VALUES
*          (2 SHIFTS)
*
PAR,1,1.83,1.65,2.2*
PAR,2,24.15,21.73,28.98*
PAR,3,19.77,17.8,23.73*
PAR,4,14.44,13,17.33*
PAR,5,15.83,14.25,19*
PAR,6,12.6,11.34,15.12*
PAR,7,5.6,5.04,6.72*
PAR,8,40.07,36.07,48.09*
PAR,9,20.65,18.58,24.78*
PAR,10,,25,30*
PAR,11,28.35,25.51,34.02*
PAR,12,.33,.3,.4*
PAR,13,4.2,3.78,5.04*
PAR,14,.87,.79,1.05*
PAR,15,5.25,4.72,6.3*
PAR,16,18.9,17,22.68*
PAR,17,8.4,7.56,10.08*
PAR,18,8.05,7.24,9.66*
PAR,19,10.15,9.13,12.18*
PAR,20,4.9,4.41,5.88*
PAR,21,7,6.3,8.4*
PAR,22,.35,.32,.42*
PAR,23,38.85,34.97,46.62*
*
*     FINISH OF ALL Q-GERT INPUT
*
FIN*
```

Parameter Data Values
(3 Shifts)

```
PAR,1,1.83,1.65,2.2*
PAR,2,11.5,10.35,13.8*
PAR,3,9.42,8.48,11.3*
PAR,4,14.44,13,17.33*
PAR,5,15.83,14.25,19*
PAR,6,6,5.4,7.2*
PAR,7,2.67,2.4,3.2*
PAR,8,19.08,17.18,22.9*
PAR,9,9.83,8.85,11.8*
PAR,10,,25,30*
PAR,11,13.5,12.15,16.2*
PAR,12,.33,.3,.4*
PAR,13,2,1.8,2.4*
PAR,14,.41,.38,.5*
PAR,15,2.5,2.25,3*
PAR,16,9,8.1,10.8*
PAR,17,4,3.6,4.8*
PAR,18,3.83,3.45,4.6*
PAR,19,4.83,4.35,5.8*
PAR,20,2.33,2.1,2.8*
PAR,21,7,6.3,8.4*
PAR,22,.35,.32,.42*
PAR,23,38.85,34.97,46.62*
```

Appendix C. Q-GERT Analysis Program Results

GERT SIMULATION PROJECT VAFBGSS   BY BENBUC
DATE 8/ 5/ 1984

FINAL RESULTS FOR 10 SIMULATIONS

AVERAGE NODE STATISTICS

NODE	LABEL	PROBABILITY	AVE.	STD.DEV.	SD OF AVE	NO OF OBS.	MIN.	MAX.	STAT TYPE
8	SRM DIE		NO VALUES RECORDED						
47	LAUNCH	1.0000	105.5624	.3060	.0968	10.	105.1913	106.2129	B

		AVERAGE NUMBER IN Q-NODE					**AVERAGE WAITING TIME**			**NUMBER IN Q-NODE**
NODE	LABEL	AVE.	STD.DEV.	SD OF AVE	MIN.	MAX.	AVE.	STD.DEV.	SD OF AVE	MAX.
12	RR	13.2966	.0046	.0015	13.2052	13.3019	709.9583	.2759	.0872	26.0000
14		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15	SEG	.0157	.0023	.0007	.0117	.0180	1.5790	.2363	.0747	1.0000
18	RR	1.6366	.0020	.0006	1.6349	1.6412	160.4942	.1942	.0614	3.0000
20		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
21	FSA	.0005	.0007	.0002	0.0000	.0020	.0943	.0689	.0218	1.0000
25	STRT STK	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
28	MICHOUD	6.4147	.0476	.0150	6.3413	6.4729	387.4483	2.0732	.5006	15.0000
30		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
58	TCF	.9271	.0008	.0003	.9259	.9286	95.9913	.0832	.0263	1.0000
26	STACKED	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
34	ET SRP	.0002	.0013	.0001	0.0000	.0007	.0201	.0287	.0091	1.0000
50	VAFEDOCK	2.6468	.0095	.0031	2.6275	2.6594	225.1950	3.1196	.9865	4.0000
53	ET STORE	3.6124	.0039	.0012	3.6030	3.6101	339.2007	4.7463	1.5009	4.0000
60		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
62	SRM STOR	.8376	.0018	.0006	.8351	.8405	84.3181	.1828	.0578	1.0000
68	PRE STAK	1.5704	.0042	.0013	1.5632	1.5771	158.0844	.4247	.1343	2.0000
70	SRSF	.0182	.0010	.0003	.0170	.0197	1.8469	.1136	.0359	1.0000
91	ORB ARR	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000
94	OMCF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
95	ORBITER	.0928	.0062	.0019	.0840	.1031	9.0904	.6550	.2074	1.0000

AVERAGE SERVER UTILIZATION / **EXTREME VALUES**

SERVER	LABEL	NO. PARALLEL SERVERS	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX. IDLE (TIME OR SERVERS)	MAX. BUSY (TIME OR SERVERS)
12	SEG XPT	1	.1467	.0034	.0011	10.	.1415	.1518	98.8071	17.2471
13	TRAIN	1	.1615	.0018	.0006	10.	.1589	.1645	97.6280	20.7289
15	SRB STAK	1	.2026	.0016	.0005	10.	.2005	.2057	90.5750	24.6754
17	BARGE	1	.3207	.0040	.0013	10.	.3153	.3295	86.8749	29.9851
18	SRB PROC	1	.4056	.0043	.0014	10.	.4043	.4176	74.7629	118.4955
92	ONCF	1	.3700	.0058	.0018	10.	.3623	.3799	132.3794	46.2093
60		1	0.0000	0.0000	0.0000	10.	0.0000	0.0000	114.2645	0.0000
18		1	0.0000	0.0000	0.0000	10.	0.0000	0.0000	113.5253	0.0000
93		1	0.0000	0.0000	0.0000	10.	0.0000	0.0000	114.5106	0.0000

AVERAGE RESOURCE UTILIZATION / **NUMBER OF RESOURCES**

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX.
1	SEGS	1.0000	0.0000	0.0000	10.	1.0000	1.0000	1.
2	SKIRTS	1.0000	0.0000	0.0000	10.	1.0000	1.0000	1.
3	BARGE	3.2637	.0090	.0028	10.	3.2503	3.2763	4.
4	LP	.9914	.0005	.0001	10.	.9907	.9921	1.
5	ONCF	.4662	.0021	.0007	10.	.4634	.4696	1.
6	ETSC	3.6124	.0039	.0012	10.	3.6038	3.6181	4.
7	ETCO	.9970	.0007	.0002	10.	.9956	.9984	1.
8	SRB STOR	.8376	.0018	.0006	10.	.8351	.8405	1.
9	SRSF	1.9982	.0004	.0001	10.	1.9976	1.9986	2.

AVERAGE RESOURCE AVAILABILITY / **NUMBER OF RESOURCES**

RESOURCE	LABEL	AVE.	STD.DEV.	SD OF AVE	NO. OF OBS.	MIN.	MAX.	MAX.
1	SEGS	0.0000	0.0000	0.0000	10.	0.0000	0.0000	0.
2	SKIRTS	0.0000	0.0000	0.0000	10.	0.0000	0.0000	0.
3	BARGE	.7363	.0090	.0028	10.	.7237	.7497	4.
4	LP	.0086	.0005	.0001	10.	.0079	.0093	1.
5	ONCF	.5338	.0021	.0007	10.	.5304	.5366	1.
6	ETSC	.3876	.0039	.0012	10.	.3819	.3962	4.
7	ETCO	.0030	.0007	.0002	10.	.0016	.0044	1.
8	SRB STOR	.1624	.0018	.0006	10.	.1595	.1649	1.
9	SRSF	.0018	.0004	.0001	10.	.0014	.0024	1.

Appendix D. Sensivity Analysis Data

CASE	LIFE	SRM	ET	XPT	ORB	SHIFT	TBL
1	100	150	60	'Y'	1	2	105.5624
2	20	150	60	'Y'	1	2	105.5624
3	5	150	60	'Y'	1	2	105.5794
4	3	150	60	'Y'	1	2	105.5325
5	2	150	60	'Y'	1	2	127.5755
6	20	15	60	'Y'	1	2	105.5624
7	20	30	60	'Y'	1	2	105.5624
8	20	210	60	'Y'	1	2	105.5624
9	20	270	60	'Y'	1	2	105.5624
10	20	365	60	'Y'	1	2	105.5624
11	20	730	60	'Y'	1	2	105.5624
12	20	3650	60	'Y'	1	2	105.5624
13	20	150	10	'Y'	1	2	105.6556
14	20	150	15	'Y'	1	2	105.6555
15	20	150	30	'Y'	1	2	105.6173
16	20	150	90	'Y'	1	2	105.9617
17	20	150	120	'Y'	1	2	118.5269
18	20	150	150	'Y'	1	2	148.0184
19	20	150	180	'Y'	1	2	177.7102
20	20	150	60	'N'	1	2	105.3712
21	20	150	60	'Y'	2	2	105.4251
22	20	150	60	'Y'	3	2	105.4251
23	20	150	60	'Y'	4	2	105.4251
24	20	150	60	'Y'	5	2	105.4251
25	20	150	60	'Y'	1	3	71.3843
26	20	150	60	'N'	1	2	105.2756
27	20	150	60	'N'	2	3	59.8479
28	20	150	60	'N'	3	3	59.8479
29	20	150	60	'N'	4	3	59.8479
30	20	150	30	'N'	2	2	105.5541
31	20	150	30	'N'	2	3	50.3710
32	100	30	30	'N'	1	3	71.4426
33	100	30	30	'N'	2	3	50.3710
34	100	30	30	'N'	3	3	50.3710
35	100	30	30	'N'	4	3	50.3710

Appendix E. Five Factor ANOVA Results

```
* * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * *
       LRATE
    BY SHIFT
       XPT
       ORB
       SRM
       LIFE
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	66.466	17	3.910	11.994	.001
SHIFT	15.691	1	15.691	48.139	.001
XPT	.018	1	.018	.056	.815
ORB	2.035	4	.509	1.560	.230
SRM	.974	7	.139	.427	.872
LIFE	.570	4	.143	.437	.780
EXPLAINED	66.466	17	3.910	11.994	.001
RESIDUAL	5.541	17	.326		
TOTAL	72.007	34	2.118		

35 CASES WERE PROCESSED.
0 CASES (0 PCT) WERE MISSING.

DUE TO EMPTY CELLS OR A SINGULAR MATRIX,
HIGHER ORDER INTERACTIONS HAVE BEEN SUPPRESSED.

* * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * *

```
          LRATE
       BY SHIFT
          XPT
          ORB
          SRM
          ET
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	68.184	20	3.409	12.484	.001
SHIFT	15.809	1	15.809	57.893	.001
XPT	.000	1	.000	.000	.988
ORB	1.467	4	.367	1.343	.303
SRM	.649	7	.093	.339	.922
ET	2.289	7	.327	1.197	.365
EXPLAINED	68.184	20	3.409	12.484	.001
RESIDUAL	3.823	14	.273		
TOTAL	72.007	34	2.118		

35 CASES WERE PROCESSED.
0 CASES (0 PCT) WERE MISSING.

DUE TO EMPTY CELLS OR A SINGULAR MATRIX,
HIGHER ORDER INTERACTIONS HAVE BEEN SUPPRESSED.

Appendix F. <u>ONEWAY</u> <u>Analyses</u> <u>Results</u>

VARIABLE LRATE
BY SHIFT

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	1	2.971	2.971	22.838	.000
WITHIN GROUPS	23	2.992	.130		
TOTAL	24	5.962			

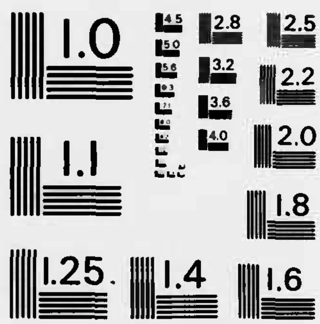
VARIABLE LRATE
BY RPT

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	1	.006	.006	.023	.882
WITHIN GROUPS	23	5.956	.259		
TOTAL	24	5.962			

AD-A148 448 IMPACT OF ACTIVATION OPTIMIZATION ON THE VANDENBERG GROUND SUPPORT SYSTEM..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. 2/2

UNCLASSIFIED G R BENFIELD ET AL. SEP 84 F/G 22/4 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

VARIABLE LRATE
BY SHIFT

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	1	62.427	62.427	215.041	0
WITHIN GROUPS	33	9.580	.290		
TOTAL	34	72.007			

GROUP	COUNT	MEAN	STAND. DEV.	STAND. ERROR	MIN.	MAX.	95 PERCENT CONF INT FOR MEAN
GRP 2	26	3.33	.35	.07	2.05	3.47	3.19 TO 3.47
GRP 3	9	6.39	.90	.30	5.08	7.25	5.69 TO 7.08
TOTAL	35	4.12			2.05	7.25	
UNGROUPED DATA			1.4[illegible]	.25			3.62 TO 4.62

VARIABLE LRATE
BY ORB

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	4	.026	.006	.022	.995
WITHIN GROUPS	20	5.937	.297		
TOTAL	24	5.962			

VARIABLE LRATE
BY SRM

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	7	.046	.007	.019	1.000
WITHIN GROUPS	17	5.916	.348		
TOTAL	24	5.962			

VARIABLE LRATE
BY LIFE

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM CF SQ.	MEAN SQ.	F RATIO	F PRCB
BETWEEN GROUPS	4	.300	.075	.265	.897
WITHIN GROUPS	20	5.662	.283		
TOTAL	24	5.962			

VARIABLE LRATE
BY FT

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM CF SQ.	MEAN SQ.	F RATIO	F PRCB
BETWEEN GROUPS	7	3.040	.434	2.526	.056
WITHIN GROUPS	17	2.922	.172		
TOTAL	24	5.962			

Appendix G. Duncan and Tukey Range Test Results

```
VARIABLE LRATE

MULTIPLE RANGE TEST

DUNCAN PROCEDURE
RANGES FOR THE .050 LEVEL -
    2.86

THE RANGES ABOVE ARE TABULAR VALUES.
THE VALUE ACTUALLY COMPARED WITH  MEAN(J)-MEAN(I) IS..
          .3810 * RANGE * SQRT(1/N(I) + 1/N(J))

HOMOGENEOUS SUBSETS  (SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS DO
NOT DIFFER BY MORE THAN THE SHORTEST SIGNIFICANT RANGE FOR A
SUBSET OF THAT SIZE)

SUBSET  1

GROUP    GRP  2
MEAN     [illegible]
- - - - - - - -

SUBSET  2

GROUP    GRP  [illegible]
MEAN     [illegible]
- - - - - - - -
```

```
VARIABLE LRATE


MULTIPLE RANGE TEST


TUKEY-HSD PROCEDURE
RANGES FOR THE .050 LEVEL -
     2.88

THE RANGES ABOVE ARE TABULAR VALUES.
THE VALUE ACTUALLY COMPARED WITH  MEAN(J)-MEAN(I) IS..
          .3810 * RANGE * SQRT(1/N(I) + 1/N(J))

HOMOGENEOUS SUBSETS  (SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS DO
NOT DIFFER BY MORE THAN THE SHORTEST SIGNFICANT RANGE FOR A
SUBSET OF THAT SIZE)

SUBSET  1

GROUP    GRP  2
MEAN     3.3276
- - - - - - - -

SUBSET  2

GROUP    GRP  3
MEAN     [illegible]
- - - - - - - -
```

Bibliography

1. Air Force Test and Evaluation Center. Memo for Record. Kirtland AFB NM: 3 June 1982.

2. Andrusyszyn, Captain John G., and Captain Brian G. Milburn. An Analysis of the Space Transportation System Launch Rate Capability Utilizing Q-GERT Simulation Techniques. MS thesis, AFIT/GSO. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, December 1982 (AD-A124 706).

3. Boggs, Wallace H. and S. T. Beddingfield. "Moonport to Spaceport: The Changing Face at KSC," Astronautics and Aeronautics, 20(7,8): 28-41 (July/August 1982).

4. Cauthen, Joseph, SRB Office. Telephone Interview. George C. Marshall Space Flight Center, Huntsville AL, 9 July 1984.

5. Coleman, Major Joseph, Associate Professor, Department of Operational Sciences, School of Engineering, Air Force Institute of Technology. Personal Interviews. Wright-Patterson AFB OH, 3 January through 31 July 1984.

6. Dankhoff, Walter, Paul Herr, and Melvin C. McIlwain. "Space Shuttle Main Engine(SSME): The 'Maturing' Process," Astronautics and Aeronautics, 20(7,8): 26-32+ (January 1983).

7. Department of the Air Force. HQ USAF Program Management Directive for DOD Space Transportation System (STS) Acquisition Activities. PMD R-S 5068(29). Washington: Government Printing Office, 22 May 1984.

8. Emory, C. William. Business Research Methods. Homewood IL: Richard D. Irwin, Inc., 1980.

9. Graham, Captain Steven, and Captain Terry W. Jones. A Q-GERT Analysis of the Space Shuttle Turnaround System at Vandenberg Air Force Base. MS thesis, LSSR 21-82. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1982 (AD-A123 808).

10. Hogan, Captain Steven, Space System Logistics Analysis Branch. Personal and Telephone Interviews. AFOTEC/LG4, Kirtland AFB NM, 13 June through 15 August 1984.

11. Joyce, C. "Shuttle Fleet is Too Small to Do the Job," New Scientist, 98:203 (28 April 1983).

12. Martin Marietta. DOD STS Ground Support System Integration. Martin Document VCR-81-252, Denver CO, 8 January 1982.

13. National Aeronautics and Space Administration. Activation Optimization. SP-OPI(82-076). John F. Kennedy Space Center, 29 March 1982.

14. Pearson, D.W. Vandenberg Shuttle Turnaround Analysis Report Number 10. Denver CO: Martin-Marietta Corporation, August 1983.

15. Pritsker, A. Alan B. Modeling and Analysis Using Q-GERT Networks. New York: John Wiley & Sons, Inc., 1979.

16. Shannon, Robert E. Systems Simulation the Art and Science. Englewood Cliffs NJ: Prentice-Hall Inc., 1975.

17. "Shuttle Facility Completion at VAFB Postponed," Aviation Week & Space Technology, 117: 108+ (20 September 1982).

18. Space Division, Air Force Systems Command. DOD STS Ground Support System Integrated Logistics Support Plan. SD-YV-0070. Los Angeles: 1 July 1982.

19. Space Division, Air Force Systems Command. Refinement of Activation Optimization. Los Angeles: 29 October 1982.

20. Stetz, Lieutenant Colonel George A. Space Transportation System. VAFB Launch and Landing Site. Vandenberg AFB CA: May 1982.

21. Vandenberg STS Launch and Landing Site Activation Optimization. Vandenberg AFB CA: Department of the Air Force, April 1982.

22. Vandenberg Support Working Group (VSWG). Meeting Minutes. Vandenberg AFB CA: 20 April 1982.

23. Vonloh, Captain John F., Chief, Space Systems Logistics Analysis Branch. Personal Interviews. AFOTEC/LG4, Kirtland AFB NM, 15-16 February 1984.

24. Yager, Colonel Walter S., Commander, Shuttle Activation Task Force. Memo for Record. Vandenberg AFB CA: 30 April 1982.

Vitae

Major Gerald R. Benfield was born on 7 June 1950 in Washington, D.C. He graduated from high school in Rockville, Maryland in 1968 and accepted an appointment to the United States Air Force Academy from which he received the degree of Bachelor of Science in Aeronautical Engineering in June 1972. Upon graduation, he received a commission in the USAF and attended Undergraduate Pilot Training at Laredo AFB, Texas. He then served as a B-52G copilot in the 69th Bomb Squadron and as Assistant Alert Force Manager for the 42nd Bomb Wing at Loring AFB, Maine. He then served as the Chief of Safety/CT-39A Instructor Pilot in the 1402 Military Airlift Squadron at Andrews AFB, Maryland prior to receiving a Joint DOD assignment to Headquarters United States European Command, in Stuttgart, Germany. He served as the Chief of Safety and the Chief of Standardization/Evaluation for the HQ USEUCOM Flight Operations Branch until entering the School of Systems and Logistics, Air Force Institute of Technology, in May 1983.

Permanent Address: 316 De La Vista
Security, Colorado 80911

Christopher James Budinsky was born on 25 July 1953 in Cleveland, Ohio. He was raised in Youngstown, Ohio, where he graduated from Ursuline High School in 1971. He received a Bachelor of Science degree in General Engineering from the United States Air Force Academy in 1975. He graduated from Undergraduate Pilot Training at Laughlin AFB, Texas, in August 1976. He was subsequently stationed at Rickenbacker AFB, Ohio, as a KC-135 copilot until the base closed to active duty personnel in July 1979. He transferred to the 963rd Airborne Warning and Control Squadron, Tinker AFB, Oklahoma, as a copilot and held additional duties as a Squadron Mobility, Athletic, and Training Officer. Upgrading to Aircraft Commander and Instructor Pilot, he flew the E-3A until entering the School of Logistics, Air Force Institute of Technology, in June 1983. He is a member of Sigma Iota Epsilon.

Permanent Address: 3416 Bentwillow Lane
Youngstown, Ohio 44511

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GSM/LSY/84S-3	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION School of Systems and Logistics 6b. OFFICE SYMBOL (If applicable) AFIT/LS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Space Systems Logistics Analysis Branch 8b. OFFICE SYMBOL (If applicable) AFOTEC/LG4S	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code) Air Force Operational Test and Evaluation Center Kirtland AFB, New Mexico 87117	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification) See Box 19	
12. PERSONAL AUTHOR(S) Gerald R. Benfield, B.S., Major, USAF Christopher J. Budinsky, B.S., Captain, USAF	
13a. TYPE OF REPORT MS Thesis 13b. TIME COVERED FROM ____ TO ____	14. DATE OF REPORT (Yr., Mo., Day) 1984 September 15. PAGE COUNT 103
16. SUPPLEMENTARY NOTATION (cont'd p 98)	Approved for public release: IAW AFR 190-17. LYNN E. WOLAVER 14 Sep 84 Dean for Research and Professional Development Air Force Institute of Technology (ATC) Wright-Patterson AFB OH 45433

17. COSATI CODES		
FIELD	GROUP	SUB. GR.
22	04	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Space Shuttle, Space Transportation System, and Space Operations, Ground Support System

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: IMPACT OF ACTIVATION OPTIMIZATION ON THE VANDENBERG GROUND SUPPORT SYSTEM USING Q-GERT ANALYSIS

Thesis Chairman: Rodney C. Byler, Major, USAF

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Rodney C. Byler, Major, USAF	22b. TELEPHONE NUMBER (Include Area Code) 513-255-5023 22c. OFFICE SYMBOL AFIT/LSM

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

(CA)

The purpose of this Thesis research was to determine the impact of the changes made to the Vandenberg AFB Ground Support System by Activation Optimization; in particular determining the annual launch rate from the Vandenberg Launch Site. A simulation approach, using Q-GERT analysis, was taken to accomplish the research objective. A Q-GERT model of the Vandenberg Ground Support System was developed and, once validated, the output used to determine the annual launch rate. Analysis of these results indicated that the Ground Support System, as changed by Activation Optimization, would be able to meet the Air Force Program Management Directive (PMD) schedule of launches for the Vandenberg Launch Site. This analysis also revealed several potential bottlenecks in the system, identifying the launch pad as the primary constraint. Further sensitivity analysis indicated, however, that for the Vandenberg Launch Site to be able to meet higher launch rates than seven launches per year the physical expansion of certain facilities must be accomplished. Originator-supplied keywords include:

END

FILMED

1-85

DTIC